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A Basis for Learning with Desktop Virtual Environments

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PhD

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Declaration

I declare that this thesis has been composed by myself and that the research reported here has been conducted by myself unless otherwise indicated.

Paul Cronin

Edinburgh, July, 27, 2000

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Abstract

An important question in current educational research concerns the effectiveness of using virtual environments (VE's) as pedagogical tools. To date no clear consensus has been reached. This is partly due to the infancy of the technology and the disparate nature of virtual environments. In this thesis a particular class of virtual environment: image-based desktop VE's, is evaluated in the context of teaching about a geology field-trip.

The thesis employs two levels of description: one theoretical and the other practical. On the theoretical level the objective is to demonstrate the effectiveness of desktop virtual learning environments for teaching and learning. Thus, a framework for learning in desktop VE's is proposed. This contains three elements: desktop virtual environments, spatial information and an eclectic pedagogical approach to learning. These elements interact with each other through three *interdependence* mechanisms: spatialisation of learning, the affordance of virtual environments for spatial information and the reification of learning. Finally these elements and mechanisms are examined through the individual cognitive differences among individuals.

Using research from spatial cognition, educational psychology and virtual environments, six experiments evaluate several hypotheses from the framework. The outcome of this research supports most aspects of the framework. The strongest features include the affordances of virtual environments for spatial information and elements of an eclectic pedagogical approach. Most interesting however are the interactive effects of individual differences on learning.

The practical level of description charts the development, design, application and evaluation of a virtual learning environment. This begins with the earliest consultations into user needs and educationalist's requirements and describes the process of transforming them into realisable educational objectives for the virtual environment. Evaluating and improving the usability of this environment forms the basis for the experiments described throughout the thesis. The practical objective is therefore to enhance the pedagogical effectiveness of a virtual learning environment by refining and evaluating its design.

In summary, desktop virtual environments are indeed effective pedagogical tools. However this is qualified by a recognition that such environments may suit certain types of learners more than others. As a description of how individuals learn, the proposed framework is quite successful. However, further refinement of experimental design is required to more completely test some of its mechanisms. The thesis concludes with proposals for developing the model further and comments on the nature of the research carried out.

Contents

1.

Introduction

1.1 Background

This thesis emerged from work carried out under the Virtual Laboratory Developers Toolkit (VLDTK) project. Begun in 1996, the project was charged with the objective to: "develop a generic set of tools and an implementation strategy that [would] provide teachers and researchers with the means to create virtual environments, virtual laboratories or virtual fieldwork in as cost-effective a way as possible to supplement or replace current practices" [extract from VLDTK proposal]. The initial aim was to develop a suite of visualisation tools for pedagogical application in Higher Education courses. These tools had to meet several requirements:

- They must be efficient
- They must show sufficient realism to be used seriously
- Be easy to use by all levels of ability
- Be assessed for educational merit
- Be available for computing platforms in HE teaching and research (e.g. Windows PC)
- Be deliverable across the Internet using WWW standards including VRML and Java

The project began by selecting three areas in which it could apply the visualisation technologies:

- Virtual fieldwork in the Geosciences
- Virtual laboratories in Veterinary Sciences and,
- Visualisation of atmospheric modeling in Meteorology

Of these, virtual fieldwork in geoscience was selected as the first pilot study. Field trips are an essential and intrinsic way of putting theory into practice in Geology. Typically the student body visits an area of geological interest. With the help of lecturers and demonstrators, they examine detail of the rock and soil structures for clues to the geological history of that location. The objective of a geology fieldtrip is to enable the student to discover evidence for generating a spatio-temporal representation of a particular location. This process combines observation of rock types and their microstructure with the gross typography of an area to form an accurate representation of its geological history. This represents an important geological goal.

However fieldtrips can lead to many financial and logistical headaches for a university department. Additional problems may arise when the student-teacher ratios are so high as to render them pedagogically ineffective while the weather can also play havoc. In contrast, simulating fieldwork in a virtual environment makes remote distance-working a reality. Moreover, it enables the disabled to participate in such activities on more equal terms than ever before. Direct savings are obvious when considering laboratory or fieldwork time. However, these have to be weighed against the extra costs of developing the virtual environments as well as the effect on students. Ultimately the greatest gains in efficiency are from re-use of the simulated environment, leaving more time for teachers to devote to individual student needs. For these reasons it was felt that a geology fieldtrip would be an appropriate educational environment to test the effectiveness of visualisation tools developed by the VLDTK project.

The implications of new technologies for teaching are an important issue in many areas of the curriculum. Interactive visualisation methods have contrasting effects on different kinds of students. The new technologies magnify existing differences. These differences can be investigated by making comparative evaluations of the effects of new and traditional methods of teaching. Thus, the educational element of the project was to make "comparative evaluations of the effects of new and traditional methods of teaching in the pilot studies. Recommendations for design improvements [would] be based on these studies" (ibid.). This implied performing educational and usability evaluation of the virtual field-courses. It is from these initial evaluations that the elements of the current thesis emerged.

1.2 Motivation

In essence it was the knowledge acquired while interacting with a virtual geology field-course along with the ability of the technology to deliver the information both usably and effectively that was being evaluated under VLDTK. This raised several interesting questions regarding the pedagogical aspects of virtual environments: What is the key educational and psychological factors involved in acquiring information from virtual reality (VR)? Could these factors be used to design more effective computer based learning environments? How important is usability design to learning in a virtual environment? To what extent is a virtual learning environment unique from other computer based and real learning environments? Similarly, to what extent are image-based desktop virtual environments (of the type used in this thesis) pedagogically similar to other more immersive virtual environments?

Within the education VR community, many of these questions have been addressed (Pantelidid, 1995; Dede, Salzman and Loftin, 1994). However, many of these studies have focused on the education aspects of VR from a bottom-up perspective. They examine specific variables to the isolation of many others. While this is a legitimate methodology, it has the disadvantage of losing sight of the general learning process and the many factors that interact with it. Furthermore, the emphasis for much VR research has been on immersive learning environments using model based geometry (see chapter 3). In contrast the VLDTK project used image-based, less immersive desktop virtual environments. While the virtues of immersive model-based environments are commonly extolled (e.g. Winn, 1997; Psotka, 1995), less is known of the potential pedagogic benefits of the virtual environments presented here.

In summary, this thesis is an attempt to describe the pedagogical interactions between the learner and desktop virtual environments using geology field-courses as a basis for learning. It builds on this description by developing a framework for describing the optimal conditions for learning with such environments. This endeavor is supported by the process of evaluating and improving the usability of the technology to achieve more effective learning experiences. These objectives may be regarded as two levels of description in the thesis: one theoretical and the other practical. Both are complimentary in progressing towards the ultimate goal of enhancing learning.

1.3 Central claims

The central claim is that image-based desktop virtual environments are as effective as multimedia and paper-based environments for acquiring and using knowledge. While perhaps not a remarkable proposition by itself, the thesis proceeds by illustrating the mechanisms by which such a claim may be made. In some contexts and for certain groups of people such environments are more effective for learning. The thesis draws from research on spatial cognition, education and virtual environments to provide several mechanisms that together may provide the optimal conditions for learning with desktop VR. These mechanisms lead to a set of hypotheses:

- Desktop virtual environments are more suited to integrating and presenting spatial information than multimedia or paper-based learning environments
- This suitably leads to a greater integration of spatial and non-spatial information in such an environment
- Desktop virtual environments are also more suited to including pedagogic features designed to improve the acquisition of non spatial information
- Individual differences are regarded as central to all other aspects of learning with a virtual environment. They have an important role to play in shaping the structure and presentation of information
- Finally, usability is an essential element in this research. All other aspects of learning are affected by the ease of use of the technology and interface. Thus any improvements made to the usability of the interface should lead to corresponding gains in the quality of learning achieved.

Besides these claims, it is equally important to stress the unique contribution that this thesis makes to describing the learning process. The research describes a set of learning experiences for a real application: geology fieldwork. The technology upon which the information is presented is evaluated in the context of this application to a degree that is not found elsewhere in the literature. Thus, overall, this thesis amounts to a comprehensive and original description of learning for a novel class of pedagogical environment in a naturalistic context.

1.4 Content

This thesis is structured into three sections. The first section extends from chapters two to four in which the background literature is described and reviewed. Chapter two reviews the literature on models of learning. It focuses on two predominant theories: constructivism and cognitivism. Cognitivism traditionally adopts the computer as a metaphor for the cognitive functioning of the brain. It proposes that knowledge is not necessarily subjectively constructed but may be acquired from sources external to the individual. Such knowledge is therefore transferable. This leads to the idea of universal learning where the same teaching practices may be administered to all individuals with similar results. The constructivist approach is partly a reaction to this though its roots go back to the work of Dewey. Constructivism holds that learning is an active process of knowledge construction in which the learner generates knowledge structures from within rather than acquiring them from external sources. This approach emphasises the importance of contextualised learning situations where authentic aspects of the task are presented to the individual in all their complexity.

Each perspective is presented as including problematic components. With cognitivism, students are often portrayed as passive recipients of knowledge with no opportunity to construct and reconstruct the knowledge for themselves. Additionally the role of social factors is not fully recognised by such theories. Criticisms of constructivism focus on the inability to transfer learning and its *radical* view of the learner as a closed organism. Clearly both models are problematic connected as they are to very different conceptions of reality. The chapter attempts to resolve this problem by proposing a set of principles for learning that are founded on pragmatism rather than dogma. This approach adopts the more successful and effective features of both perspectives. It combines them under a framework that emphasises developing a practical, pedagogical approach to teaching, learning and evaluation. This is labelled the *eclectic approach* to learning and a set of principles defining its main assumptions is described. The intention is to provide a sound basis for any model of learning with virtual environments.

Spatial cognition is examined in chapter three. The objective is to review the literature for real world environments and relate this to corresponding research in virtual environments to learn from both. The chapter begins with an overview of the structure and acquisition of spatial knowledge. While the main components of spatial cognition were not in doubt (namely landmark, route and survey knowledge), the manner of their acquisition is controversial. Following this navigation and orientation in real and virtual environments is examined. The motive is to examine what has been learned from the literature on navigation in real environments and relate it to the limited research for virtual environments. This section includes some of the main navigation aids used in both real and virtual environments. The relationship between spatial and non-spatial knowledge in cognition is then discussed regarding applications of the findings to virtual environments. Several theories are described to explain the facilitatory effects that emerge when spatial and non-spatial information is conjointly learned and integrated in memory. One of these, the Conjoint Retention Hypothesis (Kulhavy, Stock and Caterino, 1985) provides one possible explanation under dual coding processes. Other explanations for integration come from priming literature. However, the two types of integration may not necessarily depend on the same mechanisms. The potential applications for the facilitation of learning through the integration of spatial and non-spatial information in a virtual environment are also examined. The chapter concludes by examining the major individual differences anticipated in this research including differences in spatial ability and strategies of approaching information.

In chapter four the two previous reviews are brought together under virtual environments. The chapter begins with a functional decomposition of VR technology. This classifies VR by the degree of immersiveness it conveys. The discussion is extended to a description of the technology adopted for the thesis. The following section of the chapter concentrates on the pedagogical features of VR technology. The affordances provided by VR for the inclusion and acquisition of spatial knowledge are examined. Similarly the ways virtual environments provide leverage for visualising and representing information in novel and useful ways is examined. The following describes the evaluation and assessment of learning in a virtual environment. The chapter ends with a brief discussion of some additional issues including individual differences and virtual environment interfaces.

Chapters five and nine represent a second section of the thesis. These chapters summarise the main findings from what has previously been covered and extract the main themes. These themes are then discussed in relation to the main objectives of the thesis. Chapter five focuses on the three review chapters. The research is condensed and several themes are extracted to form the basis of the experimental research. These consist of:

- Affordance of spatial knowledge acquisition by virtual environments

This describes those properties of virtual environments that allow spatial information to be incorporated into their structure to ensure a seamless spatialisation of the virtual environment.

- Eclectic pedagogic model for learning and evaluation

This refers to the principles for a pragmatic approach to the design of pedagogical environments. Such principles can be applied to a VE with greater ease than a real environment given the additional flexibility for presenting information offered by virtual environments.

- Spatialisation of information

The unique spatial properties conveyed by virtual environments may contribute to the integration of spatial and non-spatial information.

- Role of individual differences

Individual differences are a factor for all of the research in the thesis.

- Usability issues with virtual reality research

Given an interaction between an individual and technology the ease of use of that technology is going to be an important variable. It is from a concern for the usability of virtual environments that the present research emerged.

From a discussion of the main research themes, a framework for learning with virtual environments is described. This framework consists of three main components: desktop virtual environments, spatial information and the eclectic learning framework. These three components are brought together by means of three further *interdependence* mechanisms. These include the spatialisation of information, affordance of virtual environments for spatial information and the reification of learning. While the first two mechanisms have already been introduced, the reification of learning is introduced as a new theme for the framework. Reification of learning refers to the unique way virtual environments provide for the visualisation, representation and manipulation of information. The technology acts as a powerful tool to work with information in ways that present new experiences for the learner. This is not thought to be possible to a similar extent with multimedia environments given their absence of spatialised structure. These components and mechanisms interact through individual differences at all levels in the learning cycle. The general hypothesis is that optimal learning will occur when all aspects of the framework are working in tandem with each other. Thus, one of the main objectives of this research is to test this prediction.

The third section of the thesis describes the experimental research. This is partly based on the hypotheses from the framework and partly on the more general objective of evaluating the design, application and usability of a virtual learning environment. The experimental research extends from chapters six to eight. Chapter six describes the early research that is based on the objectives of the VLDTK project. There the aim is to assess the need and requirements for a virtual geology field trip. The chapter opens by describing the extensive consultation exercise with the students (the end users) and the educationalists (the content providers). This is an example of the necessary background to implementing a computer-based learning tool in an educational environment. The consultation includes designing and presenting questionnaires, conducting interviews and participation in a geology field trip as an observer. The outcome of this user-needs analysis is described and from it a characterisation of the type of knowledge that must be conveyed by the virtual environment is provided. The information collated informs the design and implementation of a pilot version of the virtual learning environment. This VE based on the Siccar Point coastal area outside Edinburgh, along with its subsequent evaluation is described in the remainder of the chapter. From a cognitive standpoint the Siccar Point environment proves quite effective. Subjects learning using the experimental version with added spatial and geological features do better than controls across a number of measures of both spatial and geological ability. More exciting still is the beneficial effect that the inclusion of spatial features has for less spatially able students.

The lessons learned from the Siccar Point pilot study inform the design of the first genuine virtual learning environment described in chapter seven. This environment (set in Holyrood Park, Edinburgh), uses dedicated software to create immersive, 360°, panoramic virtual environments for desktop PC's. The Holyrood Park environment also adopts many new navigation and learning features not part of the Siccar Point study. The evaluation of this version of the geology field-course is the main focus of the chapter. It describes a large-scale project involving thirty-six people over two weeks. The outcome is that the virtual environment produces moderate learning gains on the spatial tests along with quite strong performance on a test of conceptual geological knowledge. Poor user interface design. Is blamed for performance in the spatial tests. Several additional experiments are described to test several hypotheses related to the findings of the Holyrood Park evaluation. The outcome of these experiments is that meta-cognitive learning aids enhance learning in the virtual environment. Without such aids the non-spatial benefits of the other eclectic learning features are modest. In addition, conjoint retention is shown to be present for materials learned in a real learning environment.

The research thus far establishes separate support for most of the main research themes. The key remaining issue is an evaluation of how effective each of these elements would be when required to interact with each other as proposed by the framework. The final evaluation of Holyrood Park as described in chapter eight incorporates a number of additional usability, interface and experimental design changes. The resulting experiment is designed to examine learning in the virtual environment with and without each of the key components and mechanisms of the framework. Again this is a large-scale experiment involving eight conditions and ninety-six participants. Results from this evaluation are broadly supportive of the framework. Individual differences play a major part in fashioning the results as indeed they do with all of the evaluations. The experiment also succeeds in reducing (and almost eliminating) the usability problems experienced in previous versions of the field-course and consequently satisfaction ratings are very high.

In chapter nine, the thesis returns to a discussion of the main findings from the experimental data. It begins by thematically summarising the results from the previous three experimental chapters. The findings are then compared with the predictions set out in the framework described in chapter five. Chapter ten concludes the thesis by discussing the quality of results and the flaws and problems associated with this type of research. It also makes several suggestions for future research.

2.

An Eclectic Framework for Instructional Design

Debate concerning the most appropriate pedagogical framework to adopt for teaching has long been a contentious issue in British education. Since the 1960's this debate has swung between the progressive, child-centred ideas of John Dewey on the one hand to more formal approaches to learning on the other. These two perspectives in education are rooted in alternative interpretations of reality and knowledge. The progressive view is that knowledge is constructed in the mind of the learner. The second view proposes that knowledge exists in the world and consequently the goal of learning is to incorporate as much of this knowledge as possible. These alternative perspectives of the world are known respectively as constructivism and objectivism. The motivation for this chapter lies in attempting to understand the consequences of these dominant perspectives for learning and how they might contribute to a pedagogical framework within a computer-based learning environment. The chapter begins with an overview of each of these learning perspectives. From this, a set of assumptions is presented that attempt to capture the fundamental tenets of each approach. Following this, each perspective is critically analysed and from that analysis a framework for learning, teaching and evaluation is developed. This framework captures the most effective elements of each perspective while focusing on what is pragmatic rather than dogmatic.

2.1 Information-processing approach to cognition

The information-processing approach to learning and instruction (also known as the cognitivist approach) emerged in the 1950's in reaction to the Behaviourist school of thought that had been dominant since the 1930's. Whereas Behaviourists did not attribute any functions to a mental structure, cognitivists decided to attempt to get at the root of cognitive behaviour by precisely studying the workings of the brain. Cognitive functioning is regarded as componential and therefore any study of behaviour would benefit from an understanding of the components that contributed to it. At this time, the development of the computer was becoming more widespread. This led to the adoption of the metaphor of the mind as computer. This metaphor was to prove influential on the theorising of cognitivists for the next thirty years (e.g. Atkinson and Shiffrin, 1968).

The cognitivist approach relies primarily on the mechanisms of memory for cognitive processing. While recent models view it very much as a unitary structure, it is still possible to see how the original concepts of short and long term memory are still present. The most pervasive model of short-term memory is Baddley's (1986) working memory (WM) model. This consists of a 'central executive' that controls and allocates information to a number of slave systems the most important of which are the 'visuo-spatial sketchpad' and the 'phonological loop'. These two slave systems are specialised for processing spatial and verbal information respectively. Working memory is widely regarded as the workhorse of real-time cognitive processing. WM is wholly integrated with long term memory (LTM) structures where information is stored indefinitely. LTM contains declarative and procedural information. The mechanisms by which memory processes information are based around the functions of knowledge acquisition, retention and retrieval.

The final component of learning is skill acquisition. Skill acquisition builds on memory structures and functions to produce three levels of skill competence. These levels begin with the novice stage through the associative stage and end with the autonomous or expert stage of skill acquisition (Anderson, 1983).

2.1.1 Information processing theories

As one of the earliest cognitivist models, information-processing theory (Miller, 1956, 1960) emerged from Miller's research on memory capacity. The basic unit of behaviour was the TOTE (Test-Operate-Test-Exit) (Miller, Galanter and Pribram, 1960), replacing the Behaviourist stimulus-response. The TOTE works on the basis that a test is carried out to verify that a goal has been reached. If this is not so then an operation is performed and a further test is carried out and so on until the goal is eventually reached. The theory assumes that short term memory is limited to seven chunks of information; planning is a fundamental part of behaviour and behaviour itself is hierarchically organised as chunks and TOTE's.

Given the fundamental nature of information processing theory, later models have adopted its main assumptions and incorporated them into their own frameworks. A recent example is ACT (Advanced Computer Tutoring). ACT (Anderson, 1976) describes learning as a goal-driven process. Memory is described as consisting of three principal structures: a declarative store, a procedural store and a working memory. The declarative store is represented as a semantic network containing propositions and images. All information is initially stored in the declarative area. From this, sets of conditions and actions may then be used to form productions in the procedural structure. Working memory is that part of long term memory that is currently most activated. According to ACT* (Anderson, 1983) three fundamental types of learning occur. These are labelled generalisation, discrimination and strengthening. Generalisation occurs where productions are applied to a broader range of information. The opposite occurs with discrimination where the productions become narrower in their range of application. Finally strengthening applies where certain productions are applied more often than others. ACT* has been applied to many cognitive skills including geometry proofs, programming and language learning (Anderson, 1990).

Information-processing based models also account for the role of the individual learner. Two examples are Pask's learning styles and Merrill's Component Display Theory. The learning styles perspective (Pask, 1975) emphasises the cognitive differences between individuals and how this affects their ability to learn. The differences mean that certain types of instructional materials will be best suited to some learners and not others. Similarly Merrill's Component Display Theory (CDT) (Merrill, 1983 / 1994) suggests that learning consists of two main dimensions: content and performance. This is supplemented by proposing four primary presentation forms: rules, examples, recall and practice. Secondary forms include prerequisites, objectives, helps, mnemonics and feedback. Instruction is most effective when all primary and secondary forms are used in the instructional presentation of information. The theory has been applied to a wide variety of teaching domains and materials including prescriptions for instruction at the level of course structure (Merrill, 1994).

These models offer an insight into the information-processing perspective as implemented in theoretical and practical frameworks for learning and teaching. All share assumptions about teaching and learning of which the main ones are outlined below.

2.1.2 The assumptions of the information-processing perspective

2.1.2.1 Goals and plans

Goals and plans have long been an important part of cognitivist theories of learning. They are a direct extrapolation of the mind-as-computer metaphor. There are two ways in which goals may be used for learning. First they may be used in a problem solving capacity. Thus goals are identified in the problem space and learning becomes the process of attaining those goals by effectively navigating through that problem space. The second interpretation is their capacity for structuring learning. In instructional design, goals and plans are a central part of most curricula. They establish a framework of what is to be learned. This framework is then assumed to enable the new information to be better integrated into existing knowledge. ACT*, Information Processing, and CDT all incorporate some element of plans, objectives and goals in their frameworks.

2.1.2.2 Feedback

Though not a core component, feedback is nonetheless a feature of learning that is implicit in many of the theories. In particular, Merrill's Component Display Theory values the role of feedback for enhancing learning. Feedback works on the principle that as the agent becomes better informed of the progress of its learning it can take steps to adapt learning as it deems necessary.

2.1.2.3 Global learner

The cognitivist perspective assumes people develop similar types of knowledge based on similar information being taught to them. Philosophically this allows educators to assume that the reality of learners across the world is similar and that all students will develop similar knowledge of this reality. This idea of the global learner contrasts significantly with constructivist assumptions. A more moderate view has recently been reflected in some theories such as Merrill's CDT.

2.1.2.4 Transfer of knowledge

If knowledge is contained in a knowable objective reality, then it should be transferable between learners without any loss of information. Thus ideally one should teach the abstract concepts since those are the ideas that can best be transferred and applied across tasks and situations.

2.1.2.5 Role of prior knowledge

Information-processing theories emphasise working memory as a temporary store for information required while engaged a task. Memory is also described as very modular with clearly specified processes of encoding, storage and retrieval. Similarly structural descriptions of memory are found in many cognitivist models. Long-term memory is seen as a relatively passive memory store and theories focus more on its structure than its role in influencing new knowledge creation. Some of these approaches do allow for the concept of scripts in LTM. Scrips and schema (e.g. Bartlett, 1932) are generalised rules of behaviour or cognition that have developed over time as multiple memories are consolidated and general principles are extracted from them. These cognitive structures therefore provide a possibility for new knowledge to be acted upon by prior knowledge.

Summary

The cognitivist approach assumes that knowledge resides in the world and therefore all knowledge is commonly knowable. To this idea is added the information-processing account of cognition: that the computer may be used as a metaphor for the brain. From these assumptions several models for learning have been developed which successfully characterise various aspects of cognition under the cognitivist framework. Several principles for learning and teaching are outlined to provide a succinct account of the approach. The most important of these principles included the use of goals, the importance of feedback, the role of short term memory and the concept of the universal learner. In some respects the approach has much in common with the constructivist tradition with its emphasis on the role of prior knowledge. However, these two traditions also differ in many fundamental ways. These differences again are rooted in the way people think about the world.

2.2 Constructivist approach to cognition

Constructivism may be described as radical, cognitive and social. These three descriptions differ on the locus of knowledge construction (within or without the mind), and the extent to which the constructed knowledge is an accurate representation of external reality.

"Knowledge is the result of the individualised construction of experience. This constructed reality does not necessarily accurately represent external reality". This view is the basis for radical constructivism (von Glasersfeld, 1991/5). This assumes that one can only arrive at a viable means of constructing knowledge when one considers a subjective view of reality. Von Glasersfeld cites several examples of how individuals are commonly duped by what they take to be reality. These are rooted in the belief that one can never know what true reality is like because individuals have constructed their own world and therefore live and learn by that world. This is extended to the way individuals learn since each may experience the world differently. Ultimately the manner in which one understands reality is a subjective, constructive process.

Social constructivism proposes that knowledge emerges from social interaction and language use and is thus a shared enterprise (Moshman, 1982). The main view is that the construction of knowledge is influenced by such environmental factors as the learner's prior knowledge, beliefs, culture and the context of the learning experience. Social constructivism is originally attributed to Vygotsky's social developmental theory (1978). Cognitive development was regarded as a process by which the individual learned the tools (hammers, computers, pencils) and the cultural signs (writing, mathematics) through their interactions with others that have already socialised them into their culture. This process results in the internalisation of these aspects of the socio-cultural apparatus of the learner to become part of their cognitive profile. When new information is presented to the learner it is filtered through and restructured according to these social and cultural representations. The key motivation for so doing is the idea of being within the Zone of Proximal Development (ZPD). To quote Vygotsky, this refers to "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978). Knowledge then results from social mediation with others that in turn is influenced by the social-cultural heritage of the learner.

With cognitive (moderate) constructivism, learning is a process of interpreting and constructing reality to generate an approximate representation of that reality. This reality is socially mediated. Three main assumptions characterise moderate constructivism:

- That people actively construct their own knowledge
- The purpose of cognition is to organise and make sense of one's own experience not to reflect some ontological reality
- Meaning can be socially negotiated

The first assumption recognises the importance of individual knowledge construction. Everything relates back to individual constructions. The student is the one person that has ultimate autonomy over what is learned and what gets disposed of. Ideas are considered, interpreted in relation to previous knowledge, beliefs and even culture. Concepts like cognitive conflict, scaffolding and zones of proximal development could provide motivation for knowledge construction though one must acknowledge the part played by social factors. Ultimately all such social conflict is resolved through this process of individual knowledge construction. The second and third assumptions are social in nature since they involve other people. In a communal learning environment, a high degree of consensus through the social negotiation of meaning and knowledge must be achieved. This idea of consensual understanding or intersubjectivity is recognition between the students and teacher that certain types of knowledge must be presented as 'given' to further build upon that knowledge.

2.2.1 Constructivist theories of learning and instruction

Before it became a general perspective, constructivism as a self-contained theory of learning emerged from a conference on science and maths learning in the 1950's. There Jerome Bruner outlined many of the basic ideas that were to form the main components of the theory (Bruner, 1960). According to Bruner, constructivism is an active process that involves the construction of knowledge by the student. The construction of new knowledge emerges out of prior knowledge and experiences. Learning and instruction are most effective when the student is provided with the right conditions to discover the principles. These principles are strengthened if the student then uses them in discussion (Socratic dialogue). Above all the learning process should be structured in a spiral manner so that the student is constantly building on prior knowledge to help construct new knowledge. Bruner's constructivist theory has much in common with Jean Piaget's theory of cognitive development called "genetic epistemology" (Piaget, 1929, Piaget and Inhelder, 1973).

While Bruner emphasised the cognitive nature of learning, other models have focused on the role of social factors (e.g. Vygotsky, 1962). Situated learning theory (Lave, 1988) extends the role of social information in learning by proposing that learning is a function of the activity, context and culture in which it occurs (i.e. it is situated). The authors propose that new learning should assume the complexity of the real world and thus should be situated in an authentic context. Situated learning theory has been applied to technology-based learning activities.

Many recent constructivist theories have attempted to incorporate the use of technology as a tool for learning. One example is Cognitive Flexibility theory (Spiro and Jehng, 1990). This proposes that knowledge is flexible in that it can be restructured and applied to suit different rapidly changing situations. This is based on both the ways in which knowledge is represented (along multiple perspectives) and in the processes used to act upon that knowledge (schema assembly). The theory is particularly useful for problem solving in ill-defined and complex domains and capitalises on the idea of transferring knowledge across domains. This relies on the presentation of information from multiple perspectives and through case studies representing common characteristics of the problem. Cognitive flexibility theory emphasises the use of hypertext and videodisc technologies.

Together these constructivist theories of learning provide a variety of interpretations of how constructivism may be implemented. This is partly due to the wide range of interpretations of what constitutes constructivism. To bring some coherence and structure to the approach several assumptions are described below as forming the essence of what a constructivist perspective is or should be.

2.2.2 Assumptions of the constructivist perspective

2.2.2.1 Active learning and prior knowledge

Learning is an active process of knowledge construction. Prior knowledge initiates the construction process through the need to accommodate new information with existing knowledge structures. This helps to restructure the information so that it fits within existing schemata. However the process involves more than restructuring. New and qualitatively different knowledge structures are also constructed. The active construction metaphor features prominently in all constructivist perspectives of learning.

2.2.2.2 Social interaction and collaboration

Some constructivist approaches place greater emphasis on the importance of social factors to learning. This can vary from assuming that knowledge resides in social interactions to assumptions that social interaction acts as a useful structuring and scaffolding mechanism for knowledge construction. However most constructivist perspectives adopt a less extreme view of the importance of social interactions (e.g. situated learning theory). Most believe that social interaction contributes through the sharing of ideas and experiences, and forces the need to structure ideas and arguments.

2.2.2.3 Prespecifying knowledge

Content cannot be prespecified. The learner constructs their own interpretation therefore prescribing what needs to be learned is a futile exercise. Instead all that the teacher can do is to specify the core content domain but the student is encouraged to go beyond the givens and seek new perspectives.

2.2.2.4 Contextualising learning

Constructivism proposes instantiating factual information in the context of that domain. The goal is to help the learner become an expert in the domain, not to simply acquire a list of rules and productions that might be relevant some day. Learning must be embedded in the specific task and vice versa. Contextualisation features prominently in many constructivist perspectives including anchored instruction and cognitive flexibility theory.

2.2.2.5 Control over learning lies with the learner

Learning is most effective when the information is relevant to the individual. The student must be allowed control over the pace and direction of that learning to ensure that they attend to the information they feel is relevant. This information should then be better learned than non-relevant information.

2.2.2.6 Situating cognition

Learning must be situated in real world contexts. This means that the task is part of a larger context. The reasons for doing the task must also be authentic. In short the learning must be relevant to some task. The situated learning approach carries with it several assumptions that serve to influence the other facets of constructivism. These include grounding the action in the concrete situation in which it occurs; the lack of knowledge transfer between tasks; the fact that real learning occurs only in authentic situations and therefore training by abstraction is of little use; and finally the importance of a highly social environment for good instruction (Anderson, Reder & Simon, 1998). One implication is the idea that learning should include case-based exemplars to illustrate its complexity and the relevance to the real world. One should not unduly simplify the environment to make learning easy.

2.2.2.7 Multiple perspectives

Besides the importance attached to achieving multiple perspectives of a learning situation, the students must make sure that they fully understand each of the learning perspectives and evaluate them before adopting the one that is most suitable for their own needs. There are two ways of achieving this. The first is through collaborative learning. The most important feature of collaborative learning is to understand others' perspectives. Collaborative learning is important to constructivism for the shared learning objectives of negotiating meaning. This is expressed through collective problem solving, the display of multiple roles, the confrontation of ineffective strategies, and the provision of collaborative work skills (Seely Brown, Collins & Duguid, 1990). Multiple perspectives may also be presented through examples that help to embed the learning in a realistic context: "have students see the alternative views of how a concept is seen in actual instruction" (Duffy & Jonassen, 1992).

2.2.2.8 Meta-cognitive awareness

This refers to awareness of the learning process as well as self-awareness. It can extend from an active awareness of learning and knowledge construction to an understanding of the epistemological approach that one is taking when attempting to learn. In both cases meta-cognitive awareness and reflection on learning are regarded as a very important component of constructivism.

2.2.2.9 Constructivist evaluation and assessment

The approach to evaluation that constructivism has to offer challenges many preconceived ideas. Jonassen (1992) has outlined the main constructivist criteria for evaluating learning:

- Goal-free evaluation

Goal-driven evaluation biases the outcome of the learning process. By contrast goal-free evaluation does not bias the learners objectives but supports the constructivist idea that learning is itself a constructive process.

- Authentic tasks and context-driven evaluation

If one is to design tasks that are authentic, then the evaluation of these context-dependent tasks needs to be situated in similarly contextualised environments.

- Knowledge construction

According to Jonassen (1992), "evaluators need to focus on learning outcomes that will reflect the intellectual processes of knowledge construction". This can be extended to the creation of new goals and methods for learning, solving relevant problems, and argumentation where the criterion for assessing each of these knowledge construction outcomes is originality.

- Experiential constructions

Evaluation should be intrinsic to the assumptions of learning which here consist of meaning being subjectively determined, grounded in perception and grown out of experience.

- Multiple perspectives

Evaluation should consist of a panel of evaluators from novice up to expert who would evaluate multiple learning outcomes each of is a sufficient demonstration of learning.

- Socially constructed (negotiated) meaning

The goals of learning should be negotiated as should the process of negotiation be used in the form of argumentation as evidence for learning.

Summary

This section described the constructivist tradition in education. Though it emerged as a self-contained theory, constructivism has become a generic term for a diverse collection of theories that prescribe a variety of learning techniques based on the idea of a learner-centred pedagogy. One of the main tasks in this section was to try and extract a set of principles that could be defined as constructivist in their approach. There will inevitably be critics that suggest such assumptions were never the sole property of the constructivist tradition. To a certain extent this is true and indeed the final section of this chapter appeals to this similarity between the traditions to develop a more eclectic approach to teaching and learning. However for such an exercise to be successful, there must also be recognition of the flaws that are an inherent part of these perspectives. In the next section these flaws are assessed.

2.3 Critique of theories

This section describes prominent criticisms directed at both the information-processing and constructivist perspectives. While they differ in several areas, two of the most fundamental differences relate to the decomposition and decontextualisation of knowledge. Constructivism proposes that knowledge cannot be decomposed into rules since these rules cannot be defined independently of each other (Resnick and Resnick, 1992). However, information-processing research has provided evidence illustrating both the rules themselves, the interactions between such rules and the relationships between cognitive processes and external behaviour (Anderson, Reder and Simon, 1998). This implies that systems of rules can combine and interact to produce more complex behaviour that in turn may be decomposed back into these rules. This also extends to the evaluation of learning which implies that the components of learning may be evaluated to gain a deeper understanding of the mechanisms at work.

Constructivists also reject the idea of decontextualisation. Instead learning and assessment should occur in the context in which the task will eventually be used to ensure good transfer of learning. For cognitivists context is important but only within the scope of the particular skill or concept being taught. If the decomposition of tasks is accepted, then while it might be important to teach the subtasks in the context of their immediate relevance to learning, there is no reason why the subtasks must be taught in the context of the larger domain to which they could be applied. Thus it is possible to learn the subtasks to a larger task separately and effectively without invoking the use of that subtask to a larger domain.

2.3.1 Situated Learning

This refers to the view in constructivism that learning will be enhanced if it takes place in authentic contextualised and complex learning environments. Certainly there is a significant body of research in cognitive psychology that supports the idea that the context of a situation can influence learning (e.g. Tulving's (1983) work on encoding specificity). However to generalise that all learning should be situated in its original context is not supported by information-processing theories. Furthermore, most cognitivists would argue that the ability to be able to abstract ideas from one context and apply them in another is more important (Merrill, 1994). Indeed, there are many tasks where abstract teaching is most effective. Examples include Singley (unpublished) and Biederman and Shiffrar (1987). In the latter study, the problem of sexing day-old chicks was examined, a task that can take years of apprentice learning to master. However after 20 minutes of abstract instruction it was found that novices performed as well as experts on the task. In summary, there are tasks where abstract learning is effective while there are also ones where authentic learning is also effective. The trade-off is in the objective and the cost of learning. If the learning is for a variety of tasks that share many core skills then abstract instruction might be appropriate, however if the learning is for a specific task area then specific training is advised.

2.3.2 Environmental complexity

The complexity of the learning environment is related to situated learning. Constructivists assert that effective learning will only occur if the student is presented with concepts in the context of real world complexity (Lesh and Zawojeski, 1992). However there are two problems with this idea (Anderson et al., 1998). First, if a learner experiences difficulty with the components of a task then there is a danger that processing demand may overwhelm them. Secondly, once the learner has mastered most of the components they may then waste resources going back over components they have mastered to learn those components they have not yet attempted. However, complexity is required for implementing a sense of realism in an application since the types of problems that people encounter in the real world are also complex (CTGV, 1992). Clearly a certain amount of complexity in any learning situation is desired if only to motivate and challenge students to extend and apply their prior knowledge. However there also comes a point in the learning process where too much complexity can hinder learning. The solution lies in designing courseware that is flexible enough to adapt to the learner but does not stretch those demands too far beyond core cognitive capabilities.

2.3.3 Strategy universality

Moderate constructivists view teaching and evaluation as a process by which value must be attributed to the mechanisms by which the learner came to their conclusion. This moderate view emphasises an open-ended, multi-perspective approach. However cognitivists are concerned that this open-ended approach will lead to less valid and less accurate measures of knowledge gain (Anderson et al., 1998). The main problem lies with a failure among constructivists to clearly specify the goals for learning. Without these objectives it may not be possible to ensure that learning or the evaluation of learning is fair and valid and above all bias-free. What is required is a compromise between the two views of learning. The approach adopted by information processing theorists has often failed to account for the role of individual differences in the past. However more recent models of learning have begun to recognise the importance of teaching and evaluation that is sensitive to the individuality of the learner.

Related to open-ended evaluation is the ambiguous nature of the student-teacher relationship. Constructivists (e.g. von Glasersfeld, 1991) often suggest that the student must control their own educational progression. The role of the teacher is to interpret the student's conceptual understanding. However there are going to be instances where the student's (intuitive) conceptualisations are incorrect by cultural expectations of education. In these instances the intervention of the teacher is required to set the student on the correct line of thought. If however the student were viewed as "judge" in these instances then it would be uncertain when instruction had failed.

2.3.4 Active learning

Constructivists often argue that the cognitivist view of learning implies that students passively acquire knowledge from the outside world. The information-processing theorists have largely dismissed this view of learning. Most modern cognitivist theories include a significant role for the active construction of knowledge. This was described in Anderson's ACT* theory and in Feigenbaum and Simon's (1984) EPAM model. Despite this the degree to which constructivists pursue this criticism is interesting. One reason might lie in the continuation of the passive view of knowledge acquisition in classroom design and practice. Certainly the legacy of the passive view of learning continues in rote learning, lectures and the use of other expository materials and techniques. Part of the reason for the persistence of these styles of teaching is simply their effectiveness. Students often remember information that is explicitly taught to them as well as if not better than information they construct for themselves (Slamecka and Katsaiti, 1987).

2.3.5 Collaborative learning and meaning negotiated from multiple perspectives.

For cognitivists groups do not learn, instead individuals learn. Groups may contribute to the development and structuring of knowledge but the actual construction of that knowledge occurs in the individual (Merrill, 1996). Constructivists (particularly social constructivists) claim that meaningful knowledge construction emerges out of the interaction of the individual with their environment. The elements of this social interaction include one's culture, beliefs, expectations and the dialogue that one enters with their counterparts. Knowledge is constructed through these social interactions. Indeed a significant body of research shows that new conceptions can emerge out of the collaboration of individuals while working and learning (Jonassen, 2000). In contrast, information processing accounts point out that certain tasks might be better learned individually without the distraction of cooperative learning. This is because group interaction may increase the cognitive load on the person leaving fewer resources for actually tackling the problem. This has led to a significant literature on the ineffectiveness of cooperative learning as recent reviews into this area have shown (NRC, 1994). Thus the difference between the two perspectives is in whether knowledge construction takes place through social interaction as opposed to within the mind.

2.3.6 Transfer of learning

According to constructivists, learning needs to be grounded in experience for transfer to occur though cognitivists argue that training on the abstract concepts will allow their application in other domains and situations. There have been as many successes of transfer in the literature (e.g. Brown, 1990, Brown and Campione, 1993) as failures (e.g. Gick and Holyoak, 1980, Hayes and Simon, 1977). Generally degree of transfer between tasks is determined by the representation of the transfer task and the degree of practice on the target task. It also depends on the number of symbolic components shared as Singley and Anderson (1989) discovered in their study of transfer between text editors. The authors also noted that many of the obstacles to transfer were transient. In other words the simple redirection of the attention of students led in most cases to successful transfer. Thus the direction of attention determines whether effective transfer will occur and hence training on appropriate cues to signal the relevance of an appropriate skill is important (Anderson, Reder and Simon, 1998).

2.3.7 Idealised view of the learning situation

Information processing theories claim that one can devise programmes of instruction based on the idea of human behaviour being regular, reliable, knowable, and predictable. However, this would appear to represent an idealised view of learning. ACT* and information processing theories more generally do not address some key elements of learning deemed important in the constructivist paradigm such as student motivation and attitude. Despite this both perspectives set out principles for the best approach to teaching and learning based on their theory and rely on the teacher to turn these principles into workable statements of practice.

Conclusion

The rejections of decomposition and decontextualisation are what lie at the heart of many criticisms of constructivism. It leads to a view of learning, which makes several false assumptions about information-processing and cognitive psychology. Constructivism also suffers from a number of other problems, some of which lie in its very definition as a theory of learning and instruction. These problems, what one might call the identity crisis within constructivism, mean that as an approach to teaching and learning it is difficult to define. Its scope extends so far and its assumptions are so general that even some information- processing theorists have been labelled as being constructivist (Anderson et al., 1998). Furthermore it is difficult to evaluate the approach both because many of its assumptions are flawed and because it is not always certain what is considered as part of the constructivist armoury. The emphasis in much of the research literature is on the philosophical and theoretical trappings of the theory rather than its educational effectiveness. This is suggested by pedagogical techniques that are presented as an essential part of the constructivist approach simply because the underlying philosophy predicts them. Indeed, the inefficient learning and assessment procedures promoted by constructivist approaches simply do not reflect the practical realities of modern classroom teaching.

As with constructivism, the information-processing approach is not without its problems. The most contentious of these would appear to revolve around the role of social factors and its somewhat idealised view of the learning situation. The role of social factors in cognition is one that is still unresolved by the literature. However it is clear that with the widespread adoption of the Internet, the opportunities for including social elements in education are set to multiply (McMahon, 1997). The contribution of these technologies to increasing the importance of social factors is already a significant research area (e.g. Computer Supported Cooperative Work - CSCW). Likewise the idealised view of learning assumed by information processing leads to a prescriptive approach to pedagogy that risks being inflexible when applied to real learning environments. Clearly cognitivist researchers need to acknowledge the role of the individual to a greater extent. To some extent this is already beginning to occur with theories such as Merrill's CDT. An acknowledgement of the importance of individual cognitive differences in learning is one of the main themes in this thesis. Furthermore, it forms an important part of a more eclectic approach to learning and teaching as described in the following section.

2.4 An eclectic approach to instructional design for virtual environments

From the review of the literature it is evident that there are more similarities than differences between the constructivist and information-processing perspectives. The similarity of pedagogical assumptions implies that it may be possible to find a set of principles that adopt those shared assumptions as a basis for developing a framework that encapsulates a pragmatic approach to education. In what follows, several principles for learning are set out which satisfy the assumptions and predictions from both approaches. These principles should be used to form the basis for any eclectic view of learning and instructional design.

2.4.1 Active construction of knowledge

Both perspectives give a prominent role to the construction of knowledge. Thus by most accounts, active construction of knowledge is something that is widely accepted. The implications for pedagogy are that instruction needs to be designed around a model of providing information in a structured, controlled but flexible way. Furthermore, instruction needs to be paced so that it encourages the learner to use their existing knowledge structures to understand more complex material. This follows in the tradition of Vygotsky's strategy of scaffolding within a student's zone of proximal development (ZPD). Instruction should be designed to lead the student to the limits of their ZPD within the framework set out above. This contrasts with ideas of transferring the knowledge into passive students. It also contrasts with discovery learning and exploratory instruction. Thus, for the design of a virtual environment the approach should be to provide the learner with a degree of flexibility within a structured learning framework. The learner could then choose at a fine-grained level those parts of the material that they wish to focus on but will be required to cover all aspects of the courseware on a macro level.

2.4.2 Situatedness of learning

Authentic, complex and contextualised pedagogical environments are important for learning. However, their contribution should not be overemphasised. Instructional designers should be pragmatic about the effectiveness of situated learning and use it where it will add real value to the learning experience. In those situations where the skills to be taught will be required across a variety of tasks then more abstract teaching of the general principles should be conveyed.

Part of the point of virtual environments is that they do attempt to recreate the situatedness of the environment almost as a design principle. How successful this is will depend on the fidelity of the environment. In the present research, simple desktop virtual environments on standard PC's are used. These virtual environments should recreate the original environment to a reasonable degree and provide some sense of being in the real world context. This should be contained within a conventional goal-directed framework where the componential aspects of the task are built upon as the learner progresses through the material.

2.4.3 Role of prior knowledge

The importance of prior knowledge is something recognised to varying extents by both learning perspectives. Thus the lesson for instructional designers is to acknowledge the relevance of prior knowledge and use it as a foundation for building new knowledge. This also introduces a degree of individuality in the learner since presumably different learners will bring different amounts of relevant prior knowledge to the classroom. Over time the teacher can build on relatively similar prior knowledge structures and so can make certain generalised assumptions about the learners.

2.4.4 Importance of goals

Goals are a fundamental part of the information-processing perspective but are rejected by many constructivists who argue that knowledge cannot be decomposed. This implies that exploratory, goal-free learning should be implemented. However the claims made by discovery learning are largely unsupported (Charney, Reder and Kusbit, 1990). Instead, learners need a structured learning environment with clear learning goals. Content information needs to be made relevant so that they can set about the course of action to learn that content. This is something that very few constructivists would argue with. Similarly, virtual environments need to be goal-driven in structure. While students should enjoy a certain amount of exploratory learning, the relevant content material must be brought to their attention. Such guidance in learning is crucial since contrary to constructivist pedagogy, students are not always the best people to decide what information is relevant. As the description of skill acquisition showed, novices are typically error prone in their behaviour.

2.4.5 Importance of social factors in learning

While social factors are an important component of the knowledge acquisition process, the construction of knowledge is an individual activity and should be treated as such when teaching. In introducing a social element into learning one must be always wary of the potential for negative behaviours to emerge such as free riding and ganging-up. Virtual environments can certainly accommodate a social element in learning. This can vary from the construction of online chat-rooms and bulletin boards to the development of avatars (virtual representations of real people that are online and available for communication). Again this will vary with the sophistication of the technology used and the requirements of the task.

2.4.6 Universality of learning

All learners are different in the way they approach a subject and construct knowledge. This difference is recognised by both perspectives though again to different degrees. Pedagogically, one must recognise the differences as they are present between learners. This does not preclude learners from acquiring similar representations of knowledge, but it does require sensitivity and a mechanism for attending to differences. Learners do vary in their learning styles and the domain-specific knowledge they bring to the learning situation. This knowledge may also affect newly acquired information. Therefore it is important to assess learners for the amount of prior knowledge that they bring to learning. This in turn can help the teacher deliver a more tailored teaching environment.

A virtual environment can be tailored to the specific learning styles of the students. Alternatively it can contain a measure of flexibility to appeal to different learning styles. Similarly it is possible to incorporate a measure of redundancy for those students that vary in the domain knowledge that they are bringing to the learning environment. Those students that require it can use the information at a basic level whereas more knowledgeable students can ignore the basic concepts and progress to more advanced elements.

2.4.7 Assessment and evaluation

A criticism often directed at information-processing theories is that they develop shallow or rote learning in their students. By contrast, constructivism claims to convey meaningful understanding of the concepts. Clearly both approaches to evaluation are required. For shallow learning, the most appropriate type of assessment strategy is short-answer tests that are a quick and efficient way of testing recall of facts. For deeper styles of learning essay-type answers, practical tasks and projects are more appropriate (Gipps & James, 1996).

Many of these principles of evaluation and assessment are embodied in an approach called Authentic Assessment (AA) (Rose, 1995). AA is a form of educational assessment concerned with fundamental indicators of learning such as mental models development and the ability to generate original solutions to problems. It includes an armoury of strategies such as open-ended questions, hands-on execution of experiments, computer simulations, and portfolios of student work over time.

This last strategy, the continual assessment of task performance is particularly important. Students should be informed of their performance while they are learning. Only then can they modify their behaviour for the purposes of realising the objectives of the courseware. Formative evaluation also provides students with a measure of control over their progress that motivates them to attend to the appropriate concepts to improve learning. It is common practice for AA to embed the test instrument into the learning process itself (Wiggins, 1992). Thus the strategies that students use when solving a problem should be valued almost as highly as the correct resolution of the problem itself. In this way evaluation should form a part of the learning process.

2.4.8 Self reflection on the learning process

Both perspectives advocate some form of what can be called meta-cognitive awareness: the process of thinking and being aware of one's own thought processes. Within constructivism, this process can be both conscious and unconscious. The unconscious variant is the means by which newly acquired knowledge may be related to prior knowledge structures (reflexive abstraction). On a conscious level, meta-cognition is important for informing the student of their performance (reflective awareness). Information-processing perspectives regard meta-cognitive awareness as a positive method of enabling the students to become more aware of their strategies for learning.

Teaching students the pedagogical goals so that they understand the motivation behind different teaching practices can enhance meta-cognitive awareness. Meta-cognitive awareness can also be practically implemented through the incorporation of various mechanisms into the learning process. One such mechanism is providing students with feedback during learning. The increased awareness of the progression of the learning allows them to reflect on which learning strategies work and the opportunity to modify their learning to improve their performance. This feedback may be implemented through multiple-choice questions throughout the learning material. The questions may refer to material that has just been learned and provide a quick test that acts as a check for the students to monitor their own progress. Feedback can then be provided. This simple mechanism serves the dual purpose of providing the user with feedback on the progress of their learning while elaborating the material they have acquired. This further strengthens the learning of the material.

2.4.9 Multiple perspectives in learning

Both approaches recognise the value of presenting multiple perspectives on the information. This creates a rich tapestry of knowledge and reinforces learning. In the classroom, information approached from a variety of sources will lead to more meaningful processing that will ensure greater understanding and increased retention. On a practical level this can be done with different modes of presenting material (e.g. with images, text, audio and video). These different modes of presentation elaborate on the core material and make it more memorable. Similarly, the material can be provided from different sources and in different contexts. For example information about a geological feature could be presented as a history lesson about a well-known geologist associated with the feature. This would elaborate the original memory of the geological feature making it more memorable for the learner.

2.4.10 Role of the teacher - student relationship

In keeping with constructivism, the teacher should become a facilitator of the students' ideas. Additionally they need to be a peer to the student (albeit one who has a clear idea of what is relevant). The description of the teacher as one who frames the teaching in a flexible but defined structure and helps the student focus on the relevant information combines well with the goals of the learning environment.

In virtual environments there may not be a teacher present as such. Thus the computer becomes the teacher for the student. The relationship between the computer and the user may be defined in four ways:

- Interaction *to/at* the computer

This is a unidirectional relationship in which the user not the computer assumes autonomy over the interactive process.

- Interaction *with* the computer

In this scenario the user and the computer do embark on a true interactive relationship where the computer embodies a measure of intelligence. Examples are found in expert systems and artificial neural networks.

- Interaction *around* the computer

People work and learn in and around the vicinity of the computer, which becomes the focal point of activity and the link between individuals. It may serve a variety of purposes including presenting and displaying information.

- Interaction *through* the computer

Interacting with the computer becomes so natural that the interface becomes transparent and the user interacts directly with the information in a way that corresponds to the learning goals. The benefits of this type of interaction are beginning to be found in research on the conceptual benefits of using high-end virtual reality (Winn, 1997; Osberg, 1993). Important conceptual issues include the immediacy of information, the degree of immersion experienced, the intelligence of the system, and ease of interaction. Interacting with information without having to negotiate the interface is the key to direct interaction. The challenge for the teacher is to use the existing technology to pursue interaction through the computer, treating it as a semi-invisible tool for learning rather than its focus.

Conclusion

The eclectic approach represents an attempt to formulate a set of pragmatic objectives for learning. It represents a significant departure from conventional views of educational theory that are firmly rooted in philosophical and theoretical ideas of knowledge and education. While there is much to be gained from developing a pedagogical framework, such accounts of learning can suffer from inflexibility that can stifle creativity and experimentation within education. However, such experimentation needs also to be related to learning at the pragmatic level. Idealised though ineffective methodologies should not be forced upon learners. What the approach above proposes is a framework that includes the most effective methods on a pragmatic level with sensitivity for the cognitive requirements of the individual

2.5 Chapter summary

Two dominant forces in education this century have been cognitivism and constructivism. Each perspective has its roots in an alternative epistemology. This has led to rather narrow prescriptions for pedagogic practice constrained only by a mutual failure to recognise the positive elements in each others' approach. What is required and what this chapter proposes is a fresh approach to pedagogic strategy, one that shamelessly adopts the most effective elements of the main theories while proposing a few of its own. This discussion reflects a wider malaise within educational research. The search for the next new paradigm in education is an ever-present one. Partly this is due to academic competition and partly it is due to the commercialisation of education. This leads to the formation and presentation of ill-conceived programs for education, which proclaim to be based on an understanding of cognitive functioning but are more typically shaped by the social mores of the time. This chapter approaches the problem from the opposite direction, concentrating on a pragmatic approach to effective learning in the classroom. The approach is eclectic because it embraces aspects of other perspectives that have consistently been shown to enhance learning. Above all it is framework for learning based on what works rather than what should work.

3.

Spatial Cognition in Real and Virtual Environments

This chapter addresses the role of spatial cognition in real and virtual environments. It begins with an examination of the literature on the structure and the acquisition of spatial knowledge. The unique affordances provided by virtual environments for spatial knowledge are described in relation to the provision of navigation aids. This is followed by an examination of how information may become spatialised. The chapter concludes with an overview of the role of individual differences in the research.

3.1 Structure of spatial knowledge

Spatial knowledge is represented in the brain through cognitive maps (Tolman, 1948). Cognitive maps refer to spatial representations constructed from interacting with an environment. They contain structural elements of spatial experiences that may be both analogical and propositional (Evans, 1980). Propositional representations refer to information stored as lists or associative networks based on abstract representations of meaning. Analogical information is stored as representations that are isomorphic to the structure of the information. This isomorphism is functional as opposed to being structural (Medyckyj-Scott and Blades, 1992). Cognitive maps might encode information propositionally but they can manipulate it analogically (Kosslyn and Pomerantz, 1977). As Tversky remarks, "cognitive maps may be impossible figures"(Tversky, 1992).

Cognitive maps are also hierarchical. For example, the distance between two cities in a state is judged smaller than the distance between two equally distanced cities in two different states (Stevens and Coupe, 1978). Cognitive maps may be constructed from partial or incomplete environmental information (Allen, 1978). Much knowledge on the structure and process of cognitive mapping has come from the distortions that result from encoding spatial information (Tversky, 1992). The most common of these distortions includes straightening of long, gradual curves, the squaring of non-perpendicular intersections, the aligning of non-parallel streets (Evans, 1980), cognitive perspective (Holyoak and Mah, 1982), and cognitive reference points (Sadalla, Burroghs and Staplin, 1980). Ultimately, the source of all these distortions could be a distorted representation or biased processing or both (Tversky, 1992).

Spatial knowledge is divided into landmark, route and survey knowledge (Siegel and White, 1975). Landmark knowledge may be described as "information about the visual details of specific locations in the environment"(Darken and Sibert, 1996). Such knowledge is built around objects or places in the environment that the person deems to be important. These points of reference are usually labelled landmarks (Lynch, 1960). Siegel and White refer to landmarks as "route maintaining devices" (1970), referring to their role in conserving directional information so that one may not stray too far from a route. The second type of spatial knowledge is route knowledge. MacEachren (1992) describes route knowledge as "a sequence of features and / or actions that describe a path between two unknown points". Route knowledge is similar to sequence knowledge in the way that it uses landmarks as anchors for the definition of routes. In this sense routes are indexed by virtue of the landmarks that act as their termini though this last point is somewhat contentious (Piaget and Inhelder, 1956; Lynch, 1960; Appleyard, 1970). Finally survey knowledge is considered the most abstract and complex type of spatial knowledge. MacEachren describes it as emphasising "spatial relations among places and features" (1992) while Darken and Sibert (1993) describe it as information that is configurational or topological in nature. Survey knowledge includes the location of objects in an environment in relation to a fixed reference system, the global outline of a large area such as a landmass, and Euclidean inter-object distances (Thorndyke and Hayes-Roth, 1982). This last type of knowledge is known as configuration knowledge and represents gestalt knowledge of a given environment. While configuration knowledge represents a separate element of spatial cognition, "all spatial representations are functionally landmarks connected by routes" (Siegel and White, 1970). This last point is very close to more recent theories (e.g. Montello, 1998).

While the division of spatial knowledge into landmark, route and survey knowledge is the most common example from the literature, other variations have been proposed (For example

Liben, 1991/81; Golledge, 1992; Kitchin et al., 1997). Similarly other researchers have raised doubts about the division of knowledge into three separate types (Aginsky et al., 1997; Montello, 1998).

3.2 Acquisition of spatial knowledge in real and virtual environments

The stage model of spatial knowledge acquisition (Siegel and White, 1975) has dominated the research literature for the past two decades. This model posits three main stages of spatial learning that resemble Piaget's sequence for ontogenetic development of spatial knowledge in the child (Piaget et al., 1960). The first stage consists of 'recognition in context memory'. People develop knowledge of landmarks by virtue of what the landmark will cue when they next come upon it. Therefore landmarks acquire significance due to the context in which they are learned which could be an historical association, architectural interest or proximity to a place of importance. The authors cited a neurophysiological basis for the mechanisms by which landmarks assume significance (Livingston, 1967).

Route knowledge develops once the individual has acquired information of the sequential record of the space between the start points and the destinations (Thorndyke and Hayes-Roth, 1982). This includes the number of turnings, their locations, and the action to be taken at those locations. These features also influence the difficulty with which a route is learned (Best, 1969). Siegel and White describe routes as involving a sequence of decisions about heading and bearing. Each decision-point thus represents a landmark and so routes may not exist without landmarks. Each new landmark that is learned forms a new segment of a route that in time could form a separate route. After considerable experience with traversing a route, the route may become scaled in an ordinal and interval sense. This commonly happens in everyday life when the number of miles or the length of time passed are used to estimate the distance travelled in a car (Gladwin, 1970). Scaling represents a more advanced level of knowledge for a route, and is interpreted as a precursor to the development of survey knowledge.

Once several routes have been learned, they may become interrelated. Knowledge of the areas surrounded by these routes gradually develops as scaling information becomes more accurate and one can develop some idea of the size of the area bordered by the routes. These areas are further refined into readily identifiable spatial elements such as *districts*, *edges* and *nodes* (Lynch, 1960). The scaling of the routes is important for development of survey knowledge since this enables accurate estimates of straight-line distances between landmarks. Similarly, bearing information from multiple landmarks combines to enable accurate predictions of position in relation to other locations, providing people with the ability to point in the direction of an unseen landmark.

The stage model is widely supported. For example, Evans, Marrero and Butler (1981) found that residents living in an area for one year had significantly more paths and nodes but the same number of landmarks as before in their sketch maps. Similarly, Heft (1979) reported that adults relied significantly more on landmarks to navigate their way through a novel path system initially than when they had become more familiar with it. Evidence for landmark-based learning has also come from studies examining the hierarchical structure of spatial cognition. A path-based learning sequence would lead to a network-based hierarchical structure while for landmark-based learning, a region-based structure is expected. Most evidence would appear to support region-based rather than network-based hierarchical structures (Leiser and Zilbershatz, 1989) and similarly with recognition-priming studies (McNamara, Hardy and Hirtle, 1989). However not all studies have supported the stage model or its emphasis on landmarks as precursors to acquiring route and survey knowledge (e.g. Sverlov, 1951; Khopreninova, 1956). Similarly, Appleyard (1970) noted how residents new to a Venezuelan city drew sketch maps that were predominantly sequential emphasising paths as organising principles. Garling, Book, Lindberg and Nilsson (1981) reached a similar conclusion while Devlin (1976) found that residents living in a town for one year or less produced maps that emphasised path elements as the main organising features. Residents living there for more than one year produced maps that had more landmark features and schematic boundaries. The conclusion from these studies is that landmarks cannot exist independently of routes but are learned to define a route.

Despite these findings it is very probable that other factors influence the primacy of landmarks and paths. Two important sources may be the environment (Abu-Obeid, 1998) and the role of individual cognitive differences (Aginsky, Harris, Rensink, and Beusmans, 1997). This more flexible view has inspired recent research to provide alternative models for spatial knowledge acquisition. Montello (1998) suggests a *new framework* that characterises spatial knowledge acquisition as a quantitative shift in accuracy with a single major qualitative shift from differentiated knowledge of several localised areas to a comprehensive configuration of an entire area. Individual differences are important where similar degrees of exposure to an environment will lead to differences for the integration of separately learned places.

One important question is whether spatial knowledge acquisition is similar in a virtual environment. If it is then this implies that navigation aids developed for real world orientation might be just as applicable for virtual worlds. Ruddle, Payne and Jones (1998) found evidence of route and survey knowledge acquisition using desktop virtual environments (VE's). They had their subjects navigate along a route though the virtual environment. Results showed that subjects could learn a route particularly if it contained no more than two turns. Importantly the result showed a clear development of similar spatial knowledge structures to the real world. As with real environments, spatial knowledge acquisition in virtual worlds is affected by the structure of the environment. For example Darken and Sibert (1996), using a large-scale sea-scape virtual environment, had subjects carry out five 'naïve' searches and one 'primed' search for the location of five ships. The spatial representations described in subjects' sketch maps were categorised into four types: a graph structure, square grid, anchor structure and a radial graph. Researchers found that the type of environment in which the navigation was conducted determined these spatial representations. Though the underlying environment was similar in each case, the addition of navigation aids altered subjects' search patterns considerably and consequently their cognitive representations.

One consistent trend of spatial cognition in VE's is the longer time taken to acquire spatial representations in comparison to real environments. However when a longer learning period is allowed, spatial knowledge acquired from real and virtual environments is almost indistinguishable (Waller, Hunt and Knapp, 1998). In a second experiment by Ruddle et al, (1998), subjects repeatedly navigated and learned the layout of two large virtual buildings. Results suggested that with increasing experience of the VE, subjects' spatial knowledge improved significantly indicating improved route and survey knowledge for the environment. Similarly Waller et al. (1998) examined the degree to which subjects transferred spatial knowledge acquired from a virtual maze to a real world version. Subjects learned the spatial layout of the maze in one of several treatments including: no training, map, VE desktop, VE immersive and VE long-immersive. By trial six the VE long-immersed subjects outperformed all other groups while both the VE immersed and the VE desktop groups were performing better than the map group. For route knowledge, though VE training may require longer immersion in the environment, this pays dividends with better performance over time. The problem with these findings is that insufficient trials are conducted to detect the effect. For example, Witmer, Bailey, Knerr and Parsons (1996) found that after three trials, though convergence and improvement in times were recorded, both real world and symbolic training groups did better than VE groups for learning the layout of a office building. Perhaps more trials would have resulted in a larger effect.

Another phenomenon concerns the distortion of spatial representations that result when they are acquired from immersive VE's. Errors result in an underestimation of distance representations, overestimation of directional orientation and an inability to develop any significant survey spatial knowledge. In a study using a virtual architectural walk-through, Henry (1992) found that subjects in virtual environment conditions overestimated the angle to a target they were required to point to. The more immersive the VE, the greater the estimate error. Subjects also suffered from distorted representations in their size estimates for various rooms. Interestingly, a desktop VE group performed quite well across these tests. Thus desktop VE's generate relatively accurate spatial representations of an environment while more immersive environments can often produce distortions in how spatial layouts are represented (Ruddle, Randall, Payne, and Jones, 1996; Satalich, 1995). This finding might be based on a number of artifacts of virtual environments including a truncated field of view (Henry, 1992; Alfano, 1990), a lack of proprioceptive feedback (Peterson, Wells, Furness III and Hunt, 1998; Sherrick and Cholewiak, 1986), unfamiliarity with the interface (Waller et al., 1998), a lack of learning / training exposure (Satalich, 1995; Ruddle et al., 1998) and simulator sickness (Witmer et al., 1996; Waller et al., 1998).

Summary

Siegel and White's stage model of spatial learning has been the impetus for a huge amount of research into spatial knowledge acquisition for large-scale environments. However, the theory is not without its flaws. More recent research has questioned the rigidity of the model and has suggested the need to be more flexible in understanding the nature of acquiring spatial knowledge. Spatial cognition in virtual environments parallels that in the real world, though it takes significantly longer and is susceptible to distortions. Desktop virtual environments result in relatively robust spatial knowledge acquisition. The problems with spatial cognition in VE's are probably due to several constraints, which may be overcome with significant design improvements. One issue that has been receiving much attention is the development of navigation aids.

3.3 Navigation aids in real environments

Real environment navigation aids (RENA's) consist of any feature that reduces human disorientation in the real world. These can include everything from maps, signs, compasses and global positioning systems to the use of the sun and stars. Despite this proliferation of navigation aids, by far the most important and most frequently reported upon in the literature are maps. Table 3-1 describes some of the many varieties of maps.

Maps are typically two-dimensional representations of a large-scale environment. Despite the variety of functions for which they are produced, almost all maps follow a set of design principles that ensure they are easy to read and interpret. These principles, first suggested by Biff and Lincoln (1988), are the two-point theorem, alignment principle and the forward-up equivalence principle. The two-point theorem states that a map-reader must relate two points seen on the map to the same two points in the real environment. For the alignment principle, the map must be aligned with the real world so that a line between any two points in the environment is parallel to a line drawn between the same two points on the map. This can

Map type	Description
You-are-here (YAH)	Indicate users' current location on the map with a marker.
Network maps	Schematic representation of a place (e.g. London Undergound map).
Route maps	Show main routes through an environment at the expense of information on relevant landmarks (e.g. motoring maps).
Survey maps	Survey maps are accurate in terms of distances and directions.
Thematic maps	These maps depict information on single topics.
Contour maps	Here the terrain contour is used as a cue to maintain direction.
OS maps	OS maps provide detailed, accurate information on the rural and urban landscape including most routes and landmarks.

Table 3-1: Selection of map styles.

vary between being view-aligned and world-aligned. With view-aligned positions, the map is always aligned with its top in the direction of the subject's view. This is most useful for exhaustively searching a space. When world-aligned, the map is kept in constant alignment with the co-ordinate system of the world. Thus the map appears to rotate when the subject changes direction making it harder to maintain a consistent cognitive map of the environment. This decreases the usefulness of the map as an aid for an exhaustive search. Finally, the forward-up equivalence principle states that the upward direction on the map should always show what is in front of the map-reader in the real environment. These principles provide a framework within which to guide the development and design of map-like navigation aids.

3.3.1 Representations of map knowledge

When individuals view a map of an environment, they form a mental image that is functionally isomorphic to the depiction on the real map (Evans, 1980). This image may take the form of a survey-like representation of the environment giving the user a simultaneous overview of all the spatial features (Thorndyke and Hayes-Roth, 1982). The mental representation is typically orientation-specific (Presson and Hazelrigg, 1984) and this explains why maps are made easier to use if they are aligned with the surrounding environment. Despite this there are similarities between map-acquired knowledge and knowledge acquired from direct navigation. These include regional clustering (McNamara, 1986) and a bias towards *squaring up* spatial relations (Tversky, 1981). Once acquired, the survey representation from maps may be used to perform tasks such as spatial scanning on previously learned maps to judge spatial relations. Forsey (1997) identifies three main cognitive operations that may be performed on maps including taking detours, reversing journeys and putting the components of journeys together. These operations are similar to functional characteristics exhibited by navigation-based survey knowledge such as flexibility, reversibility and transitivity. Thus on a functional level, map and direct survey knowledge are similar. It is this property that makes maps such an effective substitute for direct survey knowledge. However many differences remain, particularly in the type of survey knowledge acquired. Survey knowledge acquired from maps is represented as an aerial view of the environment. This enables accurate localisation of objects and accurate estimates of straight-line distances (Thorndyke and Hayes-Roth, 1982). In contrast, directly acquired survey knowledge provides a more detailed knowledge structure developed from bottom-up processing of the routes. This results in an orientation-free representation that can switch seamlessly from route to survey knowledge. It also allows for more accurate orienting with respect to surroundings and more accurate estimates of route distances (ibid.).

Map acquired spatial knowledge is also prone to distortions that either simplify the spatial relations of an object to its surrounding frame, or affect direction and distance estimates. Increased distance leads to increased distortion of distance estimates and decreased distortion of direction estimates, while long distances are underestimated and short distances overestimated (Lloyd, 1989b). The close correspondence between these findings for map trained subjects and directly acquired knowledge has been reported by Holyoak and Mah (1982). Similarly, other studies have reported that simplifying distortions are less severe for map learned knowledge than for directly experienced environments (Howard and Kerst, 1981; Lloyd, 1989a).

Perhaps the one area in which map acquired spatial knowledge does significantly differ from directly acquired spatial knowledge is in orientation bias (specificity). This refers to the tendency for map acquired representations to be constrained by the orientation in which the map was learned. In contrast, spatial representations acquired from direct experience are orientation free (MacEachren, 1992). While all spatial knowledge is somewhat orientation specific (Levine, 1982), most studies have found a strong consistent orientation bias. The source of this bias may have much to do with how individuals perceive the environment (McNamara, 1992). Presson, DeLange and Hazelrigg (1989) carried out a study in which subjects viewed either a small 1-metre layout at their feet or a larger 4-metre layout. Results showed that aligned judgements were much easier than contra-aligned ones on the 1-metre layout, but for the 4-metre layout there was no difference. This suggested that the subjects perceived the smaller layout as a single object while the larger layout was represented as a navigable space. This finding also applies to novel environments (Tarr and Pinker, 1989).

It is true to say that maps are the most dominant and influential form of real world navigation aid. This review of navigation and orientation aids in the real world provides the basis for evaluating and developing virtual environment navigation aids (VENA's).

3.4 Navigation aids in virtual environments

Virtual environment navigation aids (VENA's) are designed to aid the user while navigating through a virtual environment. Forsey (1997), describes a VENA as "a feature of the virtual environment that communicates...or functions in a manner beneficial to navigation". On the one hand many VENA's function in ways similar to their real world versions. Others are recognised from their real world equivalent but have been modified to take advantage of the freedom of movement in a virtual world. Finally there are a class of VENA's that do not exist in the real world. Such VENA's have developed organically in response to the novel modes of movement and navigation in a virtual environment.

3.4.1 Affordance of spatial information in virtual environments

Virtual environments use a spatial metaphor to structure and present information. The role of spatial metaphors in user interface design first appeared with the development of the desktop metaphor by Xerox Parc (Smith, Irby, Kimball, and Verplank, 1987). This was based on the idea that the interface of the computer should be treated like a normal desktop. There are several reasons for using spatial metaphors to design virtual environment user interfaces (Dieberger, 1998). First they are initially familiar to users. They relate to some object or environment that users interact within the real world. Thus the users are familiar with the interaction patterns associated with the metaphor. Humans also have strong spatial cognitive abilities, which have evolved around the way information is spatially organised in the real world. Thirdly, spatial metaphors and the spatial arrangement of information can express relationships that might be difficult, abstract or ambiguous. Thus spatial metaphors offer a rich language to express complex relationships. The final advantage is that they provide 'source domains' for other metaphors such as paths, enclosures, forbidden domains and so on, which provide a framework for navigation.

For VE's the metaphor *is* the environment. Therefore the storage, structure and presentation of information may be implemented in ways that are intuitive with what one might expect in the real world. However virtual environments can also extend the metaphor with the added degrees of freedom that are available to it. Virtual environment navigation aids reinforce the effectiveness of the spatial metaphor by capitalising on the real world constructs of the VE and the additional degrees of freedom conferred to them. This unique feature might be called the *affordance* of virtual environments for spatial information. Gibson (1986) describes the interaction of an agent with the environment as a set of *affordances* and *abilities*. Affordances are aspects of the environment that contribute to the interaction and support cognitive activity. Similarly an agent possesses abilities that represent aspects of the individual that enables it to contribute to the interaction. Affordances and abilities are therefore seen as entirely relational and essential to each other as both are to the interaction. One could say that VE's go beyond the constraints of the real world and establish a system of affordances shaped by the creativity of the virtual world-builder's imagination. In other words if it were possible to modify the VE while interacting with it then the set of objects that serve as affordances in that environment could be 'tinkered' to idiosyncratically accept the users' abilities. This could result in a more intuitive experience with the VE. Affordances may result in more effective spatial knowledge acquisition through the inclusion of virtual environment navigation aids.

There are three main types of VENA's (see Table 3-2). Non-modified VENA's refer to aids that are unchanged from their real world equivalents. Modified VENA's include aids adapted to function more effectively in a virtual environment.

Non-modified	**Modified**	**True**
Standard Maps	Interactive maps	Magic Features
Grids	Feedback signals	World In Miniature (WIM)
Signs	Traffic Lights	Toolglass & Magic lenses
Compass	Aerial/panoramic images	Scene in Hand
Global references	Metaphors	Map
Dead reckoning	Viewpoints	MUSE
Visual cues	Guides	CAVE
Spatialised audio	Trailblazing	ZOOMAP

Table 3-2: The selection and classification of Virtual Environment Navigation Aids.

Finally, true VENA's refer to navigation aids developed in response to the demands of a virtual environment and do not have any real world equivalent.

3.4.1.1 Maps

As in the real world, maps form an important class of navigation aid in VE's. Apart from unmodified maps, virtual environments also support what are described as 'interactive maps'. Interactive maps allow for interaction between the user and the virtual environment to a degree that is not possible in real environments. Interactive maps that track and display the users' movements have been developed allowing the individual to see both the configuration of the virtual environment and their position in it (Satalich, 1995). Additionally maps may be configured to adapt to both the environment and the task for which they are being used. For example, Darken and Sibert (1996) designed a map that corresponded to the VE design principle of organisational structure by superimposing a grid structure over the map.

Additionally, Ruddle Payne and Jones, (1997) compared way-finding performance using maps that displayed the same information but at different degrees of scale. Interactive maps are increasingly used by Internet companies for all manner of applications. Maps can be tailored to combine navigation information with task specific semantic information. This is an important feature since it means that people can combine spatial and content simultaneously. A good example on the web is Mapblast [http://www.mapblast.com]. Somewhat similar in function to interactive maps are aerial images that provide a topographical overview of an environment. Aerial images may be made interactive to function in ways similar to interactive maps.

Similar to maps and aerial images but unique to virtual environments are alternate viewpoints for aiding navigation in a virtual environment (Forsey, 1997). For example, book-marked viewpoints are a common feature of navigation in a VRML (Virtual Reality Modelling Language) environment. They consist of predefined scenes or views of the virtual world that the user selects from a list. This allows the user to navigate scenes consecutively as on a guided tour, or it also allows them to choose a specific scene and go directly there like a shortcut.

3.4.1.2 Compass devices

Compass devices are navigation aids that provide directional information on a global scale. They have been used by Ruddle et al. (1998) for subjects to navigate their way through virtual buildings. Other global reference indicators have been used for instantiating a sense of orientation within a virtual environment including an artificial 'sun' or 'North Star' (Darken and Sibert, 1993).

3.4.1.3 Magic features

Magic features are effectively a means of overriding an interface metaphor when efficiency is more important than realism. These features go beyond the conceptual boundaries set by the metaphor to enable the user to navigate efficiently. They are intended to work alongside a spatial metaphor but not necessarily to be a part of it. Rather they are a very useful exception to a rule. An effective magic feature is one that will not compromise the learnability of the system (Dieberger, 1995). Instead, they are used sparingly and under controlled conditions to ensure they do not disrupt the workings of the metaphor. Magic features are a necessary part of any metaphor. In the desktop interface they were used where a folder could contain another folder, and with the use of a search command to bypass the normal route through the folders to find a file. Similarly Dieberger (1998) has implemented a number of magic features into his Information City spatial metaphor. These include a doorway that transports a user to a remote destination, rather like a *teleportation* device.

3.4.2 Evaluation of VNA's

Despite the proliferation of VENA's, most research on their effectiveness has focused on map-based devices. Darken and Sibert (1996) compared search behaviour in a large-scale VE using a variety of navigation aids. Results showed that a map treatment and map+gid treatment were superior for search effectiveness than a grid-only group. However Darken later emphasised that the differences reported were trends and not significant. This is consistent with Satalich (1995) where a map during exploration of a virtual building was no more effective than control. Sometimes performance was degraded for subjects who had a map during exploration. Interestingly subjects given a map to study before entering the virtual environment performed better on the tests. This suggests that while a map is an effective navigation aid, its inclusion in a virtual environment may not result in the same enhancement as its real world counterpart. This is most likely due to the cognitive overload involved in truing to navigate while simultaneously attending to the map.

The effectiveness of a map ,may also be decided by its orientation (Darken and Sibert (1996) depending on whether it is view-aligned or world-aligned. View-aligned maps are more effective for carrying out an exhaustive search (Darken and Sibert, 1993). They allow for significantly faster and more accurate judgements of the relative direction of terrain features (Wickens, Liang, Prevett and Olmos, 1996) and users are able to position a target significantly more accurately (Barfield, Rosenberg and Furness, 1995). World-aligned maps are less effective for exhaustive searches of the environment (Darken and Sibert, 1993). Users make significantly faster judgements of a features' absolute position, misplace fewer features (Wickens et al., 1996) and find significantly more targets and maintain a more accurate flight path (Barfield et al., 1995). For the world-aligned maps the map itself appears to rotate in order that it satisfies the principle of always being aligned with the environment itself. Thus these users found it much more difficult to build up an effective cognitive spatial representation of the VE and thus were not as effective at carrying out an exhaustive search of the environment. From these findings, environment-rotated, forward-up views generate more orientation information while north-up symbol-rotated views are more effective for providing absolute positioning information. However what is really required is a navigational aid that combines the directional information of a forward-up map with the positional information of a north-up viewpoint. The effectiveness of such a VENA was demonstrated by Ruddle, Payne and Jones (1999a). Combined map- and world-aligned information significantly outperformed devices that presented either view only.

Map devices in virtual environments suffer similar degrees of orientation-specificity to real ones with direct navigation also resulting in orientation-free representations (Tlauka and Wilson, 1996). Finally presentation style is as important as the structure of a map in affecting the acquisition of spatial knowledge as Devlin and Berstein (1997) when they compared different map styles for task performance with a virtual map of a seaport. Subjects who viewed maps with the labels next to the features were significantly faster in their way-finding speed to locate a goal site.

Evaluations with other virtual navigation aids have been less fruitful. Ruddle et al. (1998) examined the effectiveness of a virtual compass for enhancing navigation performance in two virtual buildings. Including a compass did not affect spatial memory for the virtual building, while in other studies including a compass significantly degraded performance (Ruddle et al., 1999a). Insufficient training in the use of such aids is cited as one possible explanation (ibid.).

Summary

This section reviewed research on the role of real and virtual environment navigation aids in spatial cognition. It was prompted by a need to understand the ways that spatial cognition may be affected and enhanced through such aids. From the analysis of real world aids in which the importance of maps dominated, the focus shifted to virtual environment navigation aids. Through their intuitive use of the spatial metaphor, virtual environments provide a set of unique affordances for the use of spatial information. These spatial affordances provide the user with the opportunity to effectively navigate the information structure of the virtual environment. This process has led to the evolution of several unique VENA's. While many VENA's were effective for aiding knowledge acquisition, factors including cognitive overload, lack of training and the environments were found to interfere with their functioning. In the next section the role of the virtual environment in bringing together spatial and non-spatial information into a single representation is examined.

3.5 The spatialisation of information

Spatialising information describes the process of adding spatial elements to non-spatial information. It is intended to be a term of reference for describing how non-spatial information can be enriched with the provision of spatial features. This applies to both real and virtual environments, though for the latter, the opportunities for extending this area are more extensive.

The use of spatiality to improve the learning and memorisation of non-spatial information has a long history. Perhaps the most widespread application of this idea has been the method of loci. This mnemonic has been part of western civilisation since ancient Greek times and is reported by Cicero in his De Oratore (Bergen, 1999). Method of loci how an orderly arrangement of spatial locations can cue the recall of some unrelated, non-spatial information. The spatial locations may be real or imagined, but to aid recall, they should be spatially distinct from each other. The method acts as a mnemonic for learning by using the way information is stored in long-term memory. This is described by the Dual Coding hypothesis (Paivio, 1971). Dual Coding states that abstract and concrete information is stored as two codes using separate memory systems (Paivio, 1979, 1986). It also proposes links between the two codes that allow for cueing of both types of information by the other code. The hypothesis proposes that a concrete word contains both linguistic and pictorial memory traces. This ensures that there is a higher probability that the concrete word will later be recalled due to the multiple traces in different modalities (ibid). This hypothesis has been used to argue for the superiority of recall when pictures and text are learned simultaneously (Willows and Houghton, 1987).

More recently Dual Coding theory has been extended to account for the facilitative effects of conjointly learning map-based spatial and map-related textual information (Kulhavy, Brandon Lee and Caterino, 1985). One explanation for this finding, the Conjoint Retention Hypothesis (CRH) (Kulhavy and associates, 1985, 1993a,b) suggests the facilitation is due to the separation of the verbal and spatial codes in memory. Thus both the spatial codes of the map information and the verbal codes of the textual information may be used as facilitatory cues for either map or textual information.

3.5.1 Elements of CRH

The basis for the conjoint retention effect is in the structural quality of maps and the semantic features of related discourse. Both elements must interact conjointly in memory to increase the likelihood of recalling components from either memory source. The importance of the semantic qualities of related discourse to conjoint retention was described by Kulhavy et al. (1985). They had subjects write either a narrative or a structural description of a map they had previously studied. In the narrative group, subjects wrote a short story that used all the features on the map, while the structural group described the structural properties of the map. Results showed the narrative group recalled more features from the map than the structural group. This suggested that textual discourse needed to be semantically related in some way to the map features to be useful in cueing memory for the map.

Similarly the structural spatial qualities of the maps are also important for conjoint retention. Maps contain both featural and structural information. Featural information describes elements contained within the map space including labels and other location elements. Structural properties refer to the definition of the map space and include the boundaries that define the map space and the spatial relationship of the map features to the map space (Kulhavy et al., 1993a,b). Featural information facilitates memory for textual discourse whereby the additive effects of the verbal and spatial traces lead to memory (Andersen and Reder, 1979). However, recall of the featural information is also dependent on the structural properties of the map. Specific facilitation is greatest when the features are encoded as part of the structural elements of the map Schwartz and Kulhavy (1981). This central importance of map space to conjoint memory representations is explained by the 'intactness' of the map image (Kulhavy et al. 1993a). The structural elements of a map are described as isomorphic to the encoded image of the map (Kosslyn, (1986). This image, as a single representation, contains both featural and structural elements of the map. This encoding of map features within the framework of the map space produces two cognitive processing advantages:

- Cueing advantage - the spatial relations of the map image make it easier to cue related text events.
- Computational advantage - the single image acts like a memory chunk and as such, scanning of the image for different featural properties encounters no adverse computational costs.

Based on these observations, the more intact the structural qualities of a map image, the more effective it is as a cue of map-related textual descriptions.

3.5.2 Support for CRH

Kulhavy and associates have carried out several studies to test the predictions of CRH (Kulhavy et al. 1983, 1985, 1992, 1993a,b, 1994a,b). These predictions involve the structural intactness of maps and the semantic elements of map-related text. Conjoint retention of map and textual information is most effective when there is little overlap in their structural properties. However, a cueing relationship with the map elements is still required. The description that associates textual elements with map- related features while using as little of the spatial coding of the material as possible will be more effectively retrieved. This is due to the greater number of conjoint retrieval cues available to both the map and the discourse. In Kulhavy et al. (1985), subjects were presented with a map of a fictitious town. After studying the map, the subjects then wrote either a structural description including the spatial relationship of the features to each other or a narrative that included each feature shown in the map. The narrative group recalled significantly more correct map features and correctly located more of these recalled features than the structural group. This supported the prediction that textual material can cue map information only when the semantic content of the text is not part of the structural properties of the map.

The structural properties of the map are also important since it is the act of viewing them as a single image that is important for retention (Kulhavy et al., 1993a). Due to the invariant correspondence of the structural features of the map representation to the map image (Kulhavy 1993b), and the representation of the map image in memory as a single memory chunk, the more intact the featural information within the map space, the more effective will the map image be towards facilitating retention of map-related text. This structural integrity is essential to cueing map-related discourse and was tested by Kulhavy et al. (1993a) when they compared recall of map-related discourse elements between the presentation of an intact map and an individual feature representation. Results showed that 'intact' map displays resulted in the recall of significantly more discourse elements than fragmented map displays. Where feature placement on the blank map was highly accurate, recall of a discourse fragment was significantly higher lending further support for the intactness assumption. This finding was hinted at in the 1985 study where recall of discourse information was highest when subjects reported very high confidence of where a feature was located (Kulhavy et al., 1985).

The principles of conjoint retention have been extended to other adjunct displays (AD's) besides maps. Adjunct displays are any type of display that accompanies text such as diagrams, pictures, charts, graphs, knowledge maps, outlines, graphic organisers and concept maps. The presence on an AD with a related piece of text can result in improved recall and comprehension of the features contained in the text (Lambiotte, Dansereau, Cross and Reynolds, 1989). This is known as the adjunct display effect (ADE). CRH suggests that the ADE occurs AD's are structurally spatial relate features on their display with information in the text which is primarily verbal. Thus, learning a piece of text with an accompanying AD will lead to the storage of the information in memory as both a verbal and spatial code. Given the referential links between verbal and spatial memory traces, the spatial AD will act as a memory cue when the person attempts to retrieve the factual information. This leads to a greater chance of the information being recalled than if no AD were present (Kulhavy, Stock, Peterson and Klein, 1992). The importance of the spatio-conceptual structure of the AD has been shown for knowledge maps (Newbern and Dansereau, 1997). Similarly, those AD's that are more spatial should interfere to a greater extent with the concurrently presented spatial memory display and consequently lead to poorer recall than for a verbal memory disply. Robinson et al. (1999, 1996) foiund that comprehension of concept maps and graphic organisers (spatial AD's) was poorer when they were followed by a spatial memory display. Similarly comprehension of text and outlines (linear AD's) was poorer than when followed by a verbal memory display. Having to maintain two spatial codes in working memory stretched resources and so recall of information suffered as a result. Finally, support for the CRH has also been found with AD's in more ecologically valid contexts such as school classrooms (Verdi, Kulhavy, Stock, Rittschof and Johnson, 1996).

This section has provided further support for using the conjoint storage of spatial and verbal codes in memory to improve retrieval access during recall. These studies also contribute towards the idea of integrating spatial and non-spatial information in a common memory trace. This is relevant for any framework that attempts to use virtual environments as pedagogical tools. However the next section shows that there may be more than one way for integrating spatial and non-spatial information.

3.5.3 Alternatives to CRH for spatialising information

3.5.3.1 Elaboration explanations

Elaboration explanation proposes that multiple traces in memory increase the probability that information about the target item will be retrieved (Anderson & Reder, 1979). Two mechanisms are proposed. On the one hand, memory traces may overlap in memory so that they contain similar information. This leads to stronger activation of the relevant target information. Second, if information from a map and a text is related in some way, then this common information will establish multiple memory traces that share the common information. This will lead to the increased probability of activating the relevant target information at retrieval. Other explanations include the distinctiveness hypothesis (e.g. Jacoby and Craik, 1979) and the idea of integration (Glenberg and McDaniel, 1992). However both are similar to the basic elaboration hypothesis in their assumptions.

For the facilitatory effects of pictures and diagrams, the elaboration and dual coding approaches make similar predictions. Where the two approaches differ is for map-like representations. CRH assumes maps contain multiple types of stimuli that may be grouped into structural and featural information. The elaboration hypothesis can only explain the facilitatory effects of featural map information if it treats them as discrete stimuli. It does not deal with the structural properties of maps since it makes no accommodation for treating visual and verbal information as separate codes in memory. Consequently the structural quality of the map representation cannot predict the facilitatory effects of the map since it treats the information as one discrete stimulus. However Kulhavy et al. (1993a,b), found evidence for the importance of the structural integrity of maps that refutes the main claims of the elaboration hypothesis.

3.5.3.2 Selective cueing

Studies investigating the adjunct display effect (ADE) have been one source of support for the CRH. Alternative explanations include the *selective cueing* hypothesis. This states that the ADE occurs because the information is presented twice to memory, once from the AD and once from the textual passage. However this approach still does not explain why spatial AD's should be more effective than linear ones (Robinson and Kiewra, 1995).

3.5.3.3 Priming Studies

Priming relies upon the assumption that conceptual space occupies Euclidean space. Reaction times to information that is conceptually proximate should be faster than when one is primed by the other rather than if one was primed by an unrelated concept. Similarly, if spatial and semantic information are integrated in memory then a distance effect should be present in response latencies and accuracy. However if the two types of information were not integrated then no priming should occur.

This effect has been found by McNamara, Halpin and Hardy (1992a). They examined whether the spatial information about the location of cities and campus buildings would be integrated with the non-spatial descriptive facts about them. Results showed that subjects' location judgements were faster and more accurate (or both), when they were primed by a fact about a spatially proximate item. The authors refer to Andersen's (1983) model of the structure of spatial memory. This proposes that spatial memories consist of both a hierarchical, nonmetric representation that can encode categorical spatial relations, and a metric version that encodes metric spatial relations including inter-point distances and possibly a third component that encodes temporal order information (McNamara, Halpin and Hardy, 1992b). Location judgements would have to make use of the metric component to judge relative distance of cities and campus buildings. However the authors are uncertain as to the mechanism used to integrate the spatial and non-spatial information.

Fact predicates may be associated with an analogue version of the metric spatial representation. This seems to bear some resemblance to mental *image* proposed by Kulhavy et al. (1992). In this sense the integration of spatial and non-spatial information occurs when an analogue image is consulted and used as a cue for retrieving the relevant non-spatial information. However this predicts that no distance effects should be apparent. Another explanation might be that spatial propositional relations are responsible for the priming effects between spatial and non-spatial information in memory. The idea of allowing propositions to handle spatial relations is not new (Johnson Laird, 1983). However this explanation would not predict the differential order effects found for presentation of maps and text (Kulhavy et al., 1993a; Verdi et al., 1996). What is more likely is that both explanations may be true. On the one hand propositional information may be spatialised upon encoding by the incorporation of subtle metric and non-metric spatial relations. These spatial propositions may be generated because of viewing a map or other spatial adjunct display besides the map-image proposed by Kulhavy and associates. Whether such propositions would interact with this map-image or even the discourse-propositional information encoded from an accompanying passage is unclear. On the other hand they could also act as retrieval cues and further help enrich the map image. Given the referential links assumed by CRH (Kulhavy et al. 1985), spatialised propositions should cue the spatial information in the map image and thus benefit retrieval. One final possibility is that the integration found in priming studies and the conjoint retention found in the CRH studies are completely unrelated where one is a storage phenomenon while the other is effectively an encoding and retrieval process.

3.5.4 Extending spatialisation of information to desktop VE's

While encoding that spatial information from a VE is similar to the acquisition of spatial information from the real world, acquiring it from a map produces different representations (Thorndyke and Hayes-Roth, 1982). Both methods of acquiring spatial knowledge result in a configurational representation of a location but differ in its structure with maps producing images (Evans, 1980; Kulhavy et al., 1993), and knowledge acquired through direct navigation consisting of spatial propositions (Anderseon, 1983).

VE's also differ from real environments in the way that they are influenced byu the field of view (FOV). The FOV of desktop VE's in this thesis is much narrower than most immersive VE's and may generate a feeling of looking into the scene rather than of being a part of it (Ruddle, Payne and Jones, 1999). Despite this, these VE's also have the capacity to convey spatial representations similar to those acquired from direct navigation or more immersive VE's. The provision of immersive panoramic scenes and the opportunities for direct route-based navigation should contribute towards the development of propositional spatial representations.

From this analysis there are three possible scenarios for the acquisition of spatial information. The first is the acquisition of a fragmented series of propositional spatial representations from a navigation-based strategy. The second explanation suggests that subjects acquire a series of map-like images of each scene contained in the virtual environment. CRH´s predictions would only apply to the second scenario, but even then problems may still be experienced due to the inclusion of maps and aerial images in the VE. These aids could interfere with formation of scene-based representations. Subjects would be forced either to use the representation based on the aerial image or to use one of the scene-based representations when completing a spatial or semantic task. However it might also be possible that subjects could use a hybrid representation that would contain elements of each to establish cues for retrieval. Certainly there are shared features in each representation such as the outline of the environment and the location of geological features. It would be like using the aerial picture for an overview before zooming and replacing the aerial representation with the ground level representation from the scene-based images. Functionally, both representations would be similar. The third scenario is the integration of the spatial prepositional codes from the VE with the propositional codes from the text. This assumes that navigation of the VE leads to the development of spatial propositional representations rather than the scene-based images. The precedent for this scenario comes from the priming studies and research on prior knowledge (Sadowski et al., 1991/3). Integrated spatio-semantic information such as this could then be associated through referential links with the map-like, imaginal representations as formed from the aerial images. According to Sadowski, prior knowledge may take the form of conjointly stored verbal and propositional codes in memory. Such codes would be activated by the incoming propositions from encoded text and would be used to encode, store and retrieve these textual elements. Similarly, the scene based propositions of the textual passage are associated via referential links to the map image representation, where the mechanisms of the CRH then take over to produce facilitatory effects for the memory of aerial and passage-based information.

Summary

This section has focused on the spatialisation of information in learning from both real and virtual environments. The principal mechanisms for spatialisation were spatial images (dual coding/CRH) and spatialised propositions (priming research). The precise nature of how such information might be integrated in memory was examined followed by several implementation issues regarding virtual environments.

3.6 Individual differences

3.6.1 Spatial ability

Research on spatial ability extends back over 70 years to studies carried out by Kelly (1928) as part of an attempt to describe the factor-analytic structure of intelligence. In much of the literature spatial ability has become a rather generic term for any such ability to perceive and manipulate spatial information. However most studies agree that spatial ability consists of several major dimensions (Lohman, 1979). These dimensions are spatial orientation (SO), spatial visualisation (Vz) and spatial relations (SR). Spatial orientation refers to the mental manipulation of the position of stimuli while preserving their relationships and while using oneself for a reference. Spatial visualisation refers to the manipulation of the relationships of a group of stimuli to each other. Finally spatial relations refers to the ability to visualise how an object may be viewed and aligned from different perspectives (Satalich, 1995).

Typically psychometric tests are used to measure the proficiency of an individual along these spatial dimensions. For the SO dimension, a common test is 'Cards' test of the *Kit of Factor Referenced Cognitive Tests* (Ekstrom, French, Harman and Derman, 1976). Other sub-tasks from the kit are used to measure the other spatial dimensions. One in particular is the paper-folding test for the Vz dimension. Spatial relations (SR) identified by Lohman (1988) was regarded as more of a minor spatial variable than the other two. The degree to which these tests predict performance on desktop virtual environments is not certain (Waller, 1998) though spatial visualisation has been predictive of performance on a hypertext retrieval system (Vincente, Hayes and Williges, 1987).

Each of these dimensions of spatial ability make different cognitive demands on an individual. It is the degree to which these demands are met which decides a person's proficiency at spatial ability tasks (Waller, 1998). For example Just and Carpenter (1985) noted that high-spatial individuals have a faster mental rotation rate and manipulate mental images using non-canonical axes of while low-spatial individuals spent more time confirming their operations and rotate mental stimuli along the axes defined by the visual environment. Many such differences appear to revolve around the use of primarily verbal or spatial strategies (Satalich, 1995) and the efficiency with which they are employed (Roberts, Gilmore and Wood, 1997; Lohman, 1989).

Much of the literature suggests that technology typically magnifies cognitive differences in favour of high-spatial subjects (Vicente et al., 1987; Waller, 1999). However, this may not be the case for virtual environments. Virtual environments rely on a real world spatial metaphor. The first-person representation of the learner navigating through the information along with the emphasis and re-emphasis of spatial constructs through the inclusion of VENA's, may provide a better support structure for developing spatial knowledge in low-spatial learners. By contrast, a multimedia environment does not provide the same level of spatial support since it does not employ a real world spatial metaphor. Thus low-spatial subjects resort to other non-spatial strategies that may not be well supported by the environments.

3.6.2 Gender differences

Though not an area of interest in the thesis, sex differences are a source of individual variation in spatial cognition. Generally the literature has reported that males are more able than females at such tasks as mental rotation, map learning, Euclidean distance estimates and global orientation estimates. Females do not perform as well on certain spatial tasks, most notably on tasks of three-dimensional mental rotation (see Maccoby and Jacklin, 1974, and McGee, 1979 for reviews). However the literature is not altogether consistent, with many studies reporting equivalent performance between males and females across a selection of test parameters (Kimura, 1992). Given these findings, gender is controlled for in the studies of this thesis.

3.6.3 Serialist / holist information processing differences

The serialist / holist distinction for describing different learning strategies was first proposed by Pask (1975, 1988) and later adopted as a way of categorising individual's overall style of approaching information (Entwistle, 1981). Serialists adopt a bottom-up approach, treating the information as well-defined chunks that are sequentially linked and related by simple low-level links (Clarke, 1993). From these links, serialists work their way through the material to acquire higher-order information with theoretical and practical elements tend being learned separately (Ford, 1985). Embellishments to instruction such as anecdotes, illustrations and analogy are regarded as a distraction (Clarke, 1993). Holist learners approach information from a global perspective (Jonassen and Grabowski, 1993) by constructing an overview of the material and later filling in the details (Monaghan, 1998). High-order information is learned early while lower-level concepts are sampled from time to time with the general direction of learning being top-down (Ford, 1985). In contrast to serialists, holists also typically make rich use of analogy and illustration in relating different aspects of a subject. Learners are classified according to their performance on the Study Preference Questionnaire (SPQ) (Ford, 1985). Much of the research on serialist and holist learners has concentrated on attempts to match and mismatch the teaching style to the learning styles of the students. Generally, when leaning and teaching styles are matched, performance is significantly better than when they are mismatched (Pask, 1976). This also applies to computer aided instruction (CAI) environments (Rowland and Steussy, 1987).

The serialist / holist distinction has implications for this thesis at many levels. The motivation for investigating this cognitive style is to discover how individuals approach the information structures used in the alternate learning environments. An idea teaching environment for a holist learning styles would include conceptiual overviews, transfer tasks, elaborations and the synthesis of many topics (Jonassen and Grabowski, 1993). These characteristics are similar to those that suit a visualiser (interpreting graphs, searching for information and semantic networking). Verbalisers are more suited to sequential learning tasks (Kirby, Moore and Schofield, 1988). Given this relationship, one might expect holist / visualiser individuals to do better on spatial tasks in the VE conditions. By contrast the serialist / verbaliser (low spatial) individual would be expected to do better on a test of recall in the multimedia conditions.

One question that arises is whether there are procedural differences in the way holists and serialists approach the information in the learning environments. One way of answering this question is through an analysis of the data logs left by each subject as they navigate through the information. Through this analysis one might expect differences to emerge between serialists and holists in their styles of navigating through the information structure. Thus holists might pass through the information structure rapidly, while sporadically making use of some of the additional information provided for each geological feature before moving on to another part of the field-trip. Serialist learners might take a slower approach, moving through the information linearly. They are less likely to backtrack over previously visited features since they will have covered them in greater detail the first time around. These hypothetical routes through the information structures should differ between the virtual environment version and multimedia version of the field-course. If these effects are strong enough to emerge in the evaluations, then one might expect to find interesting interactions between different environments and learning style groups.

3.7 Chapter summary

The link between spatial elements of the information and enhancements to learning and memory is one that is found in the writings of the ancient Greeks when they wrote of the power of mnemonic aids. The latent power of such a learning mechanism is one that is so obvious to people that it tends not to be noticed. Likewise in education. What this chapter has attempted to show is how effective this aspect of information can be, not only to real world learning but also to learning with virtual environments. Three major themes are introduced: the affordance of virtual environments for spatial information, the spatialisation of information and individual differences. Virtual environments possess unique affordances for accommodating spatial information which lead to enhanced spatial representations. This process is aided further through the inclusion of virtual environment navigation aids. Spatialisation of information refers to ways in which non-spatial semantic information may be endowed with spatial elements to facilitate learning. Both themes illustrate how the spatiality of a virtual environment contributes to its educational efficacy. They also interact with and are affected by the third theme: individual differences. Knowledge of where one is must be qualified by knowledge of who is there. Appreciation of the power of spatial information for effective learning is magnified 100x fold by six degrees of freedom.

4.

The Pedagogy of Virtual Environments

This chapter reviews current research on the application of virtual reality technology to education. It will focus on four key areas: a general description of the main categories of Virtual Reality (VR); a focus on the technology employed in the thesis; the affordances of virtual environments for learning and evaluation; and an examination of the relevance of individual cognitive differences and interface issues for learning in a virtual environment.

4.1 A brief history of VR

The concept of Virtual Reality (VR) was first articulated by Ivan Sutherland in describing how his Ultimate Display would "make the virtual world in the window look real, sound real, feel real and respond realistically to the viewer's actions" (Sutherland, 1965). A technical precursor to this had already been built in the early Sixties. Developed by Morton Heilig to create a true mutisensory experience, the Sensorama was a prerecorded film in colour and stereo which was augmented with scent, wind and vibration (Rheingold, 1991). Sutherland (1966) followed up his Ultimate Display with the first head-mounted display (HMD). An HMD is a device that fits around the user's head and projects the virtual environment (VE) directly onto the eyes. This causes the user to feel completely immersed in the virtual environment. Sutherland's HMD, known as the *Sword of Damocles,* also featured head-tracking which meant that it would update the image of the VE to account for the user's movements. The first HMD was followed in 1971 by GROPE, the first force-feedback system developed at the University of North Carolina (UNC). In 1975, Myron Kreuger introduced the idea of *artificial reality* with his VIDEOPLACE project. Artificial reality consisted of experiments in specially designed rooms where the walls were designed to be responsive to the user's actions. This was not a technological development but more a conceptual experiment of how VR might someday contribute a completely new experience without the distraction of the technology.

Another important contribution to VR development has been flight simulators. In 1982, Thomas Furness helped to develop the Visually Coupled Airborne Systems Simulator (VCLASS). This flight simulator used an HMD that augmented the real worldview out the window with optimal flight-path and targeting information. In 1984, NASA developed the first off-the-shelf virtual environment display system that included an electronic glove as an input device. This led to the widespread development of input technologies. In the late Eighties, UNC developed several architectural walkthrough applications. These included the use of HMD's and optical trackers. In 1992, Myron Kreuger's reactive environment idea was implemented technologically with the development of the first collaborative virtual environment: the CAVE (CAVE Automatic Virtual Environment). CAVE projects stereoscopic images onto the walls of a room that surrounds the user. The individual views the images stereoscopically by wearing special goggles. More recently Augmented Reality systems have been developed. This refers to visual aids that overlay graphical information onto a display of the real world. This technology has been used to enhance a doctor's view of the ultrasound image of patient's body (Mazuryk & Gervautz, 1996).

VR has had a short though colourful history. However, it only caught the public imagination in the 1990's with the publication of Howard Rheingold's book *Virtual Reality* and the release of the film *Lawnmower Man*. The special effects of that film and the generally sensationalist reporting of VR by the media has led to misconceptions of what constitutes VR. In the section that follows the different types of VR technology are delineated.

4.2 A functional decomposition of VR

Virtual environments may be described as any class of computer-generated environment that present information of a muti-dimensional, interactive and immersive quality. Kalawsky (1996) proposed a generic model of a VR system that characterises the interaction between a person and the VE as a type of closed loop. His functional decomposition of the generic VR system begins with the *user* and the *information processing section* by which data is processed for delivery by the output interfaces. Connected to the information-processing section is the *application environment* that controls the tasks that are actually undertaken. Finally the system itself may interact with the *external environment*. This describes the real world that can be linked to the VR system. Such a model provides a useful platform from which to describe the main types of VR used in educational research.

There are two main types of virtual environments. Model-based VE's rely on polygons to display information. By contrast, image-based VR presents scenes captured from real world environments using standard camera or video equipment. These images are then edited and processed using dedicated software programs to stitch the images into 3D scenes. VR is also categorised by the quality of immersion that the system provides (Isdale, 1998; Kalawsky, 1996). Immersion refers to feelings of self-location within the virtual environment. This description leads to the classification of three main varieties of VR systems: non-immersive, semi-immersive and fully immersive VR.

4.2.1 Non-immersive VR

Non-immersive / desktop / fishbowl VR environments are predominantly delivered over a conventional desktop computer. Interaction devices typically consist of a conventional mouse, keyboard, joystick, glove devices or a space-ball. The fishbowl description refers to the distortion of the image when these environments are delivered across conventional computer monitors. This degrades the sense of immersion (presence) experienced by the user. Non-immersive virtual environments typically display high-resolution graphics. However the benefits of this are compromised by the narrow field-of-view (FOV). FOV refers to the angle of display of the screen. A wide FOV means the environment appears to surround the user and thus enhance feelings of immersion. Since a non-immersive environment is presented on a conventional display, the typical FOV is about 40°-50°.

In recent years the popularity of non-immersive VE's has exploded with the growth of the World Wide Web. This has coincided with the development of a mark-up language called VRML (virtual reality modelling language) used for the building and delivery of VR across the Internet. Furthermore, the recent developments of the JAVA programming language and its virtual reality counterpart (JAVA-3D) have further contributed to the proliferation of virtual environments over the Internet. Image-based environments have also proliferated across the Internet.

Non-immersive VR is relatively inexpensive. Additionally, the high resolution of the environment contrasts with the significantly lower quality graphics of many fully immersive systems. The main disadvantage is the lack of *presence* for the user. This is relevant to educational applications since it is partly the quality of the immersive experience that determines the amount and rate of learning achieved (e.g. Bricken, 1993).

4.2.2 Semi-immersive VR

Semi-immersive VR is characterised by a fixed wide-angle display of up to 150°. This is typically delivered using either a large screen or multiple television projection systems. Multiple participants gather in a room resembling a small film theatre and view the VR display on a large screen that curves towards them at the sides. This has the effect of providing the participant with mild feelings of being immersed, though one is always aware of the other participants. The principal advantages are a greater sense of immersion than desktop VR and very high resolutions. Furthermore, semi-immersive VR provides the opportunity for many people to simultaneously experience the same environment resulting in important educational benefits and cost-effectiveness. A commercial example of a projected VR system is the Reality Centre concept developed by SGI (one of which is based in Reading). This can also be networked with other sites.

4.2.3 Fully-immersive VR

This is the category of VR that has most captivated the popular imagination. Fully-immersive VR consists of a head-coupled visual display unit. This means that the user is completely isolated from the outside physical world. The synthetic reality of the virtual environment surrounds them. If they turn their head, the virtual world moves accordingly to give the person the feeling that they are present in the VE. Immersive VR produces the greatest sense of presence though this will vary according to the system's display resolution, field of view, update rate and image lags. Disadvantages include motion sickness induced by inappropriate update of the graphical information, poorer screen resolution than either of the other two types of VR, and various mechanical problems related to wearing heavy headgear.

Kalawsky points out that VR allows the participants to completely immerse themselves in and interact with a computer generated environment. Users experience non real-time scenarios, interaction equal or superior to that in the real world, the opportunity to repeat a task until satisfactory performance is achieved or to perform otherwise difficult or dangerous tasks in a safe environment. The most sophisticated multimedia technology does not approach the qualitative experience offered by immersive VR. It is precisely this difference that holds the key to unlocking new educational experiences through VR (Winn, 1997).

4.3 VR technology in the thesis

There were three main objectives that guided the choice of technology used in the research for this thesis. These were:

a) Off-the-shelf, easy to use and affordable software

b) Captures the full complexity of the external environment

c) Use of an Internet backbone

After reviewing several software packages, LivePicture's Reality Studio™ was chosen for developing and delivering the VE's for the present research. Reality Studio (RS) is a web-development package that allows its users to build interactive and partially immersive web-sites in a fast, user-friendly fashion. RS contains an entire development studio for designing and creating convincing immersive and fully interactive virtual field-courses using image-based rendering technology. The Reality Studio interface contains four main working areas:

Viewport - All work takes place in this area. The Viewport is used for:

- Viewing work
- Changing view modes (i.e. changing between 2D, 3D and overview modes)
- Including media files
- Switching between scenes in the virtual environment
- Placing and sizing hotspots (navigation objects)
- Arranging vistas

Project Manager (PM) - This area displays all directories and files that are currently in use. From the project manager, virtual environments can be edited, opened and closed.

Assets Browser - The main function of the assets browser is storing the media files that one may wish to add to the Viewport during a project.

World Map - The World Map shows a schematic representation of the scenes and their navigational links in a project.

Besides these features, Reality Studio contains additional tools for carrying out specific image-processing tasks. These include:

Photovista - This tool is designed to create panoramic images from photos, CD ROM images, video images and so on.

Object Modeller - With this tool one can create 3D image objects (IMOB's) for use in Reality Studio or in the Live Picture viewer.

FlashPix PhotoShop Plug-in - This is a plug-in which will enable any developer to create FlashPix images out of standard panoramas or other images. The Flash-Pix image may then be used for the panorama of a scene or as an image within the scene.

4.3.1 Using Reality Studio for virtual field-courses

The key to creating an effective field-course is to present the information in a compelling manner. This means incorporating immersion and interaction to provide a sense of being in the environment and retain the attention of the user. Smooth navigation through that environment is equally important. These objectives are achieved by carefully designing the presentation of content and methods for navigation through the content.

The goal of content presentation is to make learning enjoyable and easy. RS addresses these requirements with a vast media library that, using the appropriate tools, can be used to create a very engaging virtual field-course. The main media types available in RS are:

- Vistas - 360_ panoramic images.
- URL's - describe the location and name of the object file and the path to access it..
- Sounds - a sound file, usually in WAV format.
- Scripted movies - VRML files that add non random behaviours to a scene.
- Image objects (IMOB's) - image-based 3D objects.
- Movies - movie clips can be triggered to play upon entering a specific vista. They can also be triggered to play manually or automatically.
- Lighting - can be used to adjust the lighting in a scene .
- Images - consist of static GIF, animated GIF, JPEG or BMP files.
- Geometry - 3D VRML objects that may be texture mapped.
- Frames - a rectangular image used as a border for the window in the Web page.
- FlashPix images - a hierarchical image file in which one can zoom into increasingly higher resolutions to see greater levels of detail.

- Buttons - used as navigation and interaction objects.

Each media type can be used separately or with each other in a project. The most important of these is the vista. This defines the boundaries of the virtual environment. In a typical project several vistas might be linked together to form the scenes of a field-course. Other media files may be added to the vista. They endow the virtual environment with multimedia functionality. The main objective in doing so is to create a convincing degree of interaction and immersion for the user.

Spatial orientation is a vitally important component of learning in virtual environments. Without knowledge of where one is in the environment, the user soon becomes confused and anxious while their acquisition of other information may also be degraded (Psotka, 1996). For these reasons the provision of virtual environment navigation aids (VENA's) are an essential component of the structure of any virtual field-course.

In RS the user adopts a viewpoint from the centre of a scene. From there they can rotate 360_ and zoom in and out of any part of the scene but they never actually move about in it. Instead RS creates the illusion of movement. The main navigation device in RS is the *hotspot*. Its most important function is for moving from one scene to another. The hotspot offers the user two ways of navigating between scenes. These vary between 'cutting' from one scene to another, or 'panning and zooming' where the scene pans around to the desired exit-point before zooming towards the new location. The pan-and-zoom technique maintains a degree of continuity from one scene to the next. Recent studies suggest that discontinuity when navigating between locations leads to disorientation (Ruddle, 1999b). Continuity can also be affected by the proximity of one location to another. Thus it is necessary to create vistas that are just within visual contact of each other.

An example of a VENA developed using the tools of RS is the compass feature. This consists of a simple display pasted on to the vista showing the main cardinal points of reference: north, south, east and west. Thus whenever the user turns to a particular direction they are made aware of the general direction in which they are facing by the cardinal points. Additionally, the cardinal direction points may be substituted for landmarks familiar to the user or even place-names of locations.

Survey and ground-level views of a location are important for giving the user spatial awareness of both their relation to the other features in the environment and of their absolute position. VENA's fulfilling this need include simple 2D maps or aerial images of the virtual environment on which the various features and numbers denoting the different location panoramas are shown. These locations can be highlighted to show where the user currently is. They can also act like magic. features, so that when the user clicks on a number they are *teleported* to that location. To ensure continuity between the 2D overview and the 3D ground level environment, location numbers on the map correspond to hotspots on the ground. Numbering is used to control the order in which locations are visited. The Siccar Point virtual environment (chapter 6) presents an early version of these ideas. More advanced displays using 3D models of the environment are included in the Holyrood Park environments (chapters 7 and 8).

VENA's are also required for ground level navigation. Navigation through the VE can be structured either linearly or free-form. In the former, navigation is constrained to a pre-set path. This is most effective when the user is a novice at the stage of familiarising himself or herself with the virtual environment. It is also very useful if the content developer wishes the user to visit scenes that are conceptually related to each other. As the user becomes more experienced they may first wish to visit those locations that are of most relevance to them. Here free-form navigation is more suitable where the user is free to explore the environment in any order. With increased freedom of movement the risks of becoming disoriented also increase. One way of overcoming this is to incorporate a set of navigation icons throughout the virtual environment such as *back*, *forward* and *home*. These could incorporate some kind of history of where the user has been so that they do not revisit locations accidentally.

Finally, the sense of spatial familiarity can be enhanced with the inclusion of a context- setting scene or map of the entire environment that is about to be explored. In the Siccar Point environment, one begins with a map of the North Berwick coast with the Siccar Point area highlighted by the rectangular box. When one clicks inside this box, the user is transported to the Siccar Point area.

As this section demonstrates, the use to which the technology is put is as important as the technology itself. In the next section this discussion is extended to an examination of the importance of virtual reality to education.

4.4 The pedagogy of VR

The intersection of VR and education is important to the development of both disciplines. Education shapes the ways in which VR technology evolves and filters down to the individual. Similarly VR enriches the educational experience by empowering the learner with novel ways of approaching information.

4.4.1 Why VR can benefit education and vice versa

VR is a valuable tool in the eyes of an educationalist. The source of this value lies in several fundamental features of virtual environments that meaningfully contribute to enhancing the educational experience. VR provides a flexible framework for cultivating learning that is experiential, intuitive, flexible, structured, contextual, social and interactive (Bricken, 1990). These qualities relate closely to those outlined in the eclectic learning framework. First VR is experiential. Individuals live in a multi-sensory spatial environment in which all learning experiences occur. VR takes these first-person experiences and builds upon them within a similarly experiential environment. The fundamental principles of immersion and interaction with the activity and its environment remain. Bruner (1986) and Piaget (1929) have advocated the importance of actualising learning through making it real for the student. Secondly, VR environments allow intuitive, human-computer interaction using the same systems of affordances and abilities (Gibson, 1986) as are used in the real world. Affordances result in a more intuitive experience with the VE. The theory of affordances can also be extended to describe how abstract ideas may be transformed into natural semantic experiences that are easier to comprehend. If one thinks of incomprehensible concepts as affordances that do not map onto a learner's abilities, then it can be seen how the modification of one component in the affordance-ability interaction will affect the other elements.

The third component of VE's that is relevant for educational applications is that they can be a shared experience. Johnson, Johnson and Stanne (1985) describe cases in which collaboration among students contributes to an improved learning environment. Similarly, Dalton (1990) notes that it is the quality of the collaboration that is the key factor for learning rather than just collaboration per se. More practical attempts to improve the level of collaboration have involved the establishment of localised newsgroups for students that might be involved in a mutual VE task (Resnick, 1996).

Bricken (1990) suggests that VE's unlock a plethora of unique new experiences. This is possible through a multiplicity of methods including the transduction of information, multi-sensory experiences and multiple perspectives of the same object. Grove (1995) taught secondary school children Greek history through VR. Different conceptual perspectives of the same historical occurrence illustrated the way different historians have alternate versions of the past. Other opportunities for unique experience stem from the possibility for non-real time visualisation of processes, and finally to interact intuitively and naturally with objects at any level of magnification (what Bricken calls the *natural semantics* of VR). Thus, VR provides a qualitatively different learning experience than that associated with any other educational tool. A fifth feature of the way VE's support educational experiences is that they can be tailored to the individual. The definition of the individual learner was referred to in both chapters two and three in relation to differences in cognitive styles. The flexibility of the VE means that is can support a broad range of learning styles or alternatively can be tailored to the needs of a specific style. An extension of this is where the environment may be responsive to an individual's learning style and subsequently 'learns' to adapt to it (Hynes and Valley, 1995).

Kalawsky (1996) has elaborated further on these educational attributes by highlighting the opportunities for exploration (both spatially and semantically), performance assessment, sense of scale, simulation, repeatability and abstract representation with virtual environments. This final attribute also refers to the ability to manipulate abstract ideas and simplify them into more concrete and semantically intuitive presentations of information. Again the similarities with principles for eclectic pedagogy are apparent. Other features such as the self-paced acquisition of new information, the opportunity for insights, experience with new technologies and the encouragement of active participation rather than passivity among students further contribute to the educational experience (Pantelidid, 1995).

VR also benefits learning and training in practical ways. These include teaching airline pilots how to fly an aeroplane in an flight simulator (Psotka, 1995), and training firemen how to tackle a burning building (Witmer, Bailey, Knerr and Parsons, 1996). In other situations where observation of internal structure is an important aid to understanding, VR can provide direct interaction with these internal workings. Finally VR may be of significant benefit to applications that are so complex that conventional teaching methods are inadequate. These include teaching of quantum mechanics or learning about the bonding process of atoms and molecules (e.g. the

Science Space project - Dede, 1994).

4.4.2 Transfer of learning from VR

The ultimate test for the effectiveness of virtual environments as teaching and learning tools is the degree to which the learning transfers to real environments. In teaching chemistry to high school students, Byrne (1996) found that students in a VR condition performed no better than students using an interactive multimedia program on a Macintosh. It was subsequently noted that several design flaws may have contributed to the poor performance of the VR students. More positively, Psotka (1995) describes a growing body of research demonstrating support for the ability to transfer learning and training from VR to the external environment. For example, Goldberg (1994) showed that a virtual building was almost as effective as a real one for learning route information. Similarly Magee (1994) created a VR system to train junior navy officers in the conning skills required to keep ships in formation during manoeuvres and battle drills. Upon evaluation against traditional training techniques, the VR systems proved to be superior for providing improved training at a lower cost.

An important issue with the transfer of learning is the ability of the learner to adjust from the virtual to the real world situation. Kalawsky (1996) points out that there is a potential danger the learner may become used to practising a task in the relative safety of a virtual environment. This may breed complacency in the way that the skill or task is acquired and learned. When that learner is required to apply their learning to the real world, such complacency may put the learner and others at risk because of their actions. This issue has had to be addressed for airline pilots learning how to fly with a flight simulator (Psotka, 1995). Thus when pilots crash a virtual aircraft, they are grounded until an investigation into the causes of the crash is completed (much as would happen in real life). This strategy encourages the trainee pilots to take the flight simulator and their actions within it as seriously as they would with a real aircraft.

Ultimately the effectiveness of transferring learning from virtual environments will depend on two issues: the level of immersion (or more accurately *presence* experienced by the user), and the degree of interaction afforded by the environment to the user. These are closely related to each other since the less immersive a virtual environment is, the more important interaction becomes.

4.4.3 Immersion

Immersion refers to the feelings of being present within the computer-generated environment of the VR system. Research into the psychological and human factors issues of immersion are only just beginning to be studied seriously (Psotka, 1995). Despite this a growing body of literature points to intriguing differences in the way immersion can be induced and experienced. Effective immersion requires the ability to control attention and focus on what is going on in the VE while simultaneously excluding all interference from the outside world. Despite this it is relatively easy to induce immersion in the user especially in systems that use HMD's (Kalawsky, 1996). Peoples' experience of immersion (referred to as the amount of *presence* experienced) varies considerably even within the same system. This emphasises the way individual differences can affect the quality of the subjective experience. Similarly, Psotka and Davison (1993) refer to technological limitations as responsible for bringing out temperamental differences between people.

The realism of an environment, while important, is not sufficient to induce a sense of presence. As an example, Grove (1996), used a desktop VE for teaching history to school age children. In that study pupils did not regard the VE as a genuine representation of reality. Instead they treated it more as a game-like environment than as a representation of the world. Including constraints such as collision detection (an attempt to augment the realism of the virtual world) were actually counterproductive and tended to cause frustration among the students. This was based upon the students' disbelief that the VE represented anything more than a computer game with good quality graphics. The efforts to make it more realistic failed because they were based on different conceptual models of the environment to that which the students had constructed. Thus attempts to consolidate a sense of reality and increase feelings of presence will fail unless they are sensitive and flexible enough to adapt to the individual learner.

With high immersion, attention is focused and so there is greater likelihood that users will learn more and with greater ease than with traditional media (Slater & Wilbur, 1997). In Reality Studio the panoramic vista creates the basic immersive structure. However to bring the vista to life and enhance the sense of presence within, multimedia functionality is required. RS contains a selection of media that may be used to enhance presence in the virtual field-courses of the thesis.

4.4.3.1 Movies

Movies can be scripted or non-scripted and can contain sound or be silent. They can be used in a variety of learning contexts such as presenting a virtual teacher or cyber-guide to the learner. This was developed for the Siccar Point environment (chapter 6) where the geology professor is filmed speaking about the geological features in the field-course. While speaking, he points towards the relevant feature as the camera zooms in. Another use of the movie format is the development of a fly-through movie of Holyrood Park (developed as part of the VLDTK project by John Blair-Fish).

4.4.3.2 Images

Animated images can help describe temporal-based processes such as growth in living organisms or erosion and deposition in geology. They can be either manual or automatic. With a manual animated image, the user initiates the sequence for the animation. An example is contained in the Siccar Point field trip.

4.4.3.3 Sounds (ambient and localised)

The main function of ambient sounds is to enhance the realism and immersive quality of the environment. Ambient sounds can take the form of background noise such as birds singing or weather noises such as the wind. Ambient noises are used to good effect in the Siccar Point environment where one can hear waves crashing against the rocks. Sound clips can also be presented directly to the user as a running commentary as found in both the Siccar Point and Holyrood Park environments.

4.4.3.4 VRML

VRML objects are 3D web-based geometric models that can be fully explored by the user. A colleague, Gordon Watson, developed a multimedia VRML-based model of Holyrood Park as part of the VLDTK project.

4.4.3.5 Icons

Icons can have a variety of functions within RS. In the Siccar Point and Holyrood Park environments they are used primarily as navigation links similar to those found on a web browser. They are also used within a panorama to denote the existence of additional media files that may be requested. These include camera icons for referring to images and icons of a loud-speaker to denote a sound file. Other uses for icons include activating assessment tests, links to external web pages and images of spatial terms of reference such as compass points. Along with immersion, the amount of interaction provided by the technology will decide how interesting and usable the learner finds the interface.

4.4.4 Interaction

Interaction gives the user a sense of freedom and control over their learning. RS supports interactive learning through its system of triggering actions. All of the media described above can be given a degree of interactivity in RS. These actions include making a media object appear, disappear, play, stop playing, loop, and activate web links and hotspots. When triggers are combined with the various media, the applications to which the interactive components of RS can be put are endless. The nature and complexity of the interactions will vary with the content being employed, the complexity of the scene and the more pragmatic constraints of the network connection.

One useful interactive feature in a virtual environment is a *toolbar* that might feature icons referring to the interactive elements available on the page. The toolbar is created with each icon being provided with a different interactive trigger for the elements contained in a scene. Meaningful, simple icons are the most effective way to present such information. If it is found that icons are not sufficiently informative, they can be substituted with descriptive labels. Toolbars and icons alike are used extensively in the virtual field-courses. A more intuitive type of interaction with the environment is through direct manipulation of the elements. Here several interactive gestures are related to various objects in the environment. The user simply clicks on the objects and they trigger the interactive features. These can be made standard throughout every scene so that the user knows exactly what will happen when they click on an object. For example, when the user clicks on a non-specific area such as the sky, this might trigger an audio clip describing the features contained within that scene. Another possibility might be to have an audio clip start playing when the user enters a scene and for it to play once. This might be a general introduction informing the user of the interesting features to be found in that scene. This was extensively used in the Holyrood Park environments (chapters seven and eight).

Another example of an interactive feature is a *head-up* map display providing the user with their current location. The location information is updated when the user moves around the virtual environment. The map display can be designed either to be always present or to be toggled on and off as required. Extensive use of a map/aerial display is made in all of the virtual environments in the thesis. Other widely used devices include progress assessment tests. Using either the toolbar or direct manipulation, it is possible to create a link to a multiple-choice test on the knowledge expected to have been acquired from that scene. This feature could prove very useful in that it provides the student with direct access to a test of their knowledge. They could also be provided with immediate feedback on their progress, which in turn could influence how they approach their learning of the rest of the material. Examples are shown in the Siccar Point and Holyrood Park virtual field-courses.

Interaction as with immersion is an essential component for learning in virtual environments. When dealing with the less immersive desktop VR, interaction assumes a more important role than immersion to enabling effective learning to occur. Interaction is fundamental to learning for several reasons. First it is a natural means of learning for most people. Individuals learn by asking questions, experimenting with objects and problem-solving. They build on the feedback by incorporating it into knowledge structures and using that experience when attempting a similar problem in the future (e.g. Jonassen, 1992; Winn, 1997). Interaction also refers to active learning. It is widely accepted that active learning such as seeking out the information or learning by example is an integral part of learning (Jonassen, 1992; Anderson, 1993). It is this preference for acting on information (Winn, 1997) that renders direct interaction an important educational component of the RS field-course. Through interacting with various components of the virtual environment, the learner may direct more of their attention to the cause-effect relationships in that virtual world. This in turn may contribute towards a feeling of actually being a part of that world which may further enhance the feelings of presence in the environment. Thus a suggestion for designers might be to make full use of the interactive features of a virtual environment especially one that by its technological limitations is relative non-immersive.

4.4.5 VR and education - some potential pitfalls

The literature is generally positive regarding the benefits of VR to education, however the technology is not without its problems. Among those weaknesses cited by Kalawsky (1996) is the poor interface quality that low cost (especially desktop) VR systems suffer from. This filters down to the provision of a generally poorer learning experience for the user. Though desktop VR provides high resolution images, a lack of immersion will result in a poorer quality learning experience compared with more immersive VR tools (Psotka, 1995). The lack of immersion at the low end of the market is further compounded if inappropriate interface tools are used. Kawalsky states that the "mouse and keyboard are almost useless for interaction in a VE". Instead input devices with at least six degrees of freedom so that the functionality of the input device maps on to the 3D environment portrayed on the screen are recommended.

One of the principle problems with virtual reality systems is their relative cost. While the cost of a non-immersive environment starts at around £500, higher-end immersive systems can be very expensive indeed. Related to this are the costs for maintaining the technology. Technological obsolescence becomes more important with high-end technology. The issue of cost is closely related to the effectiveness of VR for educational use. One of the challenges for VR is to clearly demonstrate its effectiveness as a teaching tool, especially where educational institutions on tight budgets are concerned (Kalawsky, 1996).

One final problem with the introduction of VR is the impact on organisational change on the educational institution. The drive to cut costs and improve the teaching efficiency may increase pressure to replace some parts of the curriculum with technology. Indeed the potential effectiveness of VR to provide realistic education and training environments for students may also prove to be the greatest reason for resisting it. Thus where VR is introduced, it should be preceded with a consultative approach involving all members of the teaching staff. Education in the benefits that VR technology can bring to the teaching situation should be highlighted.

Summary

This section began by setting out the main affordances that virtual environments bring to the learning situation. These were described as its experiential, interactive and immersive qualities. This discussion was extended to examine several advantages and disadvantages of using virtual environments for education and training more generally. In addition the possibility of learning transfer was examined. Finally, the twin issues of immersion and interaction were related to the virtual worlds in the thesis. It was found that a higher degree of interaction in the environment can sometimes compensate for lower levels of immersion. In the following section the evaluation of the learning is examined at both the general level and with respect to the virtual environments of the thesis.

4.5 Evaluation and assessment in VR

The approach to evaluation and assessment adopted for this thesis is based on the principles of the eclectic model for learning outlined in chapter 2. It proposes that such evaluation should be both goal-directed and componential, where the process and the product of the learning should be assessed. VR technology is ideally suited to implementing this approach since it can be incorporated seamlessly into the learning experience (Wiggins, 1992).

Evaluation and assessment are structured on four levels in the thesis:

- standalone baseline tests of cognitive style
- evaluation of the spatial knowledge acquired
- evaluation of the conceptual knowledge acquired
- evaluation of the usability issues surrounding interaction with the technology

Each of these strands is based on the components of the knowledge as proposed by the relevant research in each area. The content and structure of the actual tests also vary to some extent from one evaluation of the virtual environment to another. Though this raises the potential problem of non-comparison of results across tests, it is balanced by an attempt to improve their validity. This highlights the evolutionary nature of the methodology. This is inevitable given the novelty of the technology and the application to which it is put.

The evaluation methodology includes both structured and unstructured methods, while also focusing on the learning process. Structured evaluation techniques are used extensively throughout. Since they are easy to administer and log online. The evaluation of knowledge acquired from the virtual environments is completely web-based to make the collection and analysis of the data more efficient. Structured techniques are also useful where the learning is relatively shallow and does not require deep understanding of the information. Structured methods are also informative and reliable.

Unstructured evaluation methods are also an important component of the evaluation methodology. For example some tests included a comments box and requested participants to include information on how they went about answering the test questions. This was intended to provide insight into the process by which participants completed the test. This attempt to understand the process of learning is a key part of the general evaluation methodology and is implemented in several ways. One of the most important attempts is through the provision of 'embedded feedback questions' (EFQ's). EFQ's are electronic multiple-choice questions incorporated into the textual descriptions that accompany each geological feature. Having read the description of the feature, the learner is then encouraged to consult the relevant EFQ for that feature. The question is of moderate difficulty and refers to information contained in the description. Beneath the question, four to five possible answers are presented. The task for the subject is to decide which of the answers is correct.

EFQ's are important for two reasons. First they are a means by which the learners can receive feedback on their own performance as they explore the environment. This allows them to adapt their learning strategy to improve understanding. Secondly, the use of the questions and the answers attempted is digitally logged. Thus one can extract information on the extent to which the learner clicked on incorrect answers before they arrived at the correct one; the number of correct answers that they clicked the first time and the pattern of performance on such questions over time. Evaluating the process of learning provides the educator and the learner alike with a rich tapestry of information on the evolution of knowledge structures. One way of thinking about it might be to compare such tests with the images from MRI and PET scans of the human brain while engaged on a task. This process-based approach is underscored by more general use of the data logs. These logs are an electronic version of an observation methodology. Analysis can be as detailed as required and can yield an extensive amount of information on the behaviour of the learner as they progress through the VE. This information can add an extra dimension to the data evaluated in more structured tests and can further support inferences drawn from such tests.

Process-based information is also relevant for usability purposes. Usability refers to the extent that the user found the interface and technology intuitive and easy to use. A usable piece of technology is dependent on its design features. For the virtual field-course the main design features are encapsulated by the design of the user interface. The main objectives in such design are that the interface should be:

- intuitive
- easy to use
- easy to navigate

The degree to which these objectives are achieved is evaluated primarily through qualitative data (e.g. questionnaires and interviews). However sometimes questionnaires may not reveal enough information, nor is the information always reliable. Thus process-oriented techniques are very useful since they clearly show a user's progress through the virtual environment. Process-based information can inform questionnaire data and ultimately contribute to a more accurate understanding of the learning process.

This section has introduced a pragmatic and effective evaluation methodology for this thesis. This generally eclectic approach to evaluation is ideally suited to virtual environments because they are easy to administer and efficient for recording the relevant data.

4.6 Individual differences and interface issues

4.6.1 Individual differences

The potential for individual differences in the interaction and learning styles of people to affect VR evaluation is considerable. As research in this area matures, a comprehensive description of the alternate cognitive styles adopted by people is emerging. While this issue has been examined in the two previous chapters, individual cognitive differences also emerge through interaction styles mediated by the type of interface controls used (Waller, 1998). Dede, Salzman and Loftin (1994) observed differences in students' ability to interact with a VE using 3D interface controls. While some students easily adapted to using menus, manipulating objects and navigating smoothly, others needed assistance throughout their virtual experience. Multiple short learning experiences rather than covering several topics in a single session resulted in fewer problems and more effective learning. Similarly, Berne, Holland, Moffit, Hodas and Furness (1996), acknowledged that students differed in their style of learning when interacting with a VR-based HIV/AIDS education programme. While some learned best by listening to lectures and reading, others did not follow this type of learning style. Such students were more visual and kinaesthetic in how they approached new information. It is to these students that the authors felt VR offered real educational benefits and in which the most significant learning gains may be achieved.

This thesis also focuses on differences between learners on their spatial ability and in the way that they approach information (either serialist or holist learners). Assessment of spatial ability is important since a virtual environment is inherently spatial in the way with which it presents information. Research indicates that the spatiality of the VE can affect cognitive spatial factors. This is supported by the literature on hypertext navigation (Oberlander, Inder, Cox and Tobin, 1997) and on the effects of logical reasoning within graphical environments (Cox, Stenning and Oberlander, 1994). The real question is to what extent VE's magnify or decrease any existing differences in knowledge acquisition because of the differences in spatial ability.

This also applies to the serialist / holist differences among individuals in the way they approach information. These differences may have some consequences for how well individuals acquire conceptual information in a virtual environment.

4.6.2 Interface issues

The interface is the medium between the user and the computer. Any change to the interface will have an impact on the quality of the interactive experience. Some interface tools are inadequate in their attempts to connect the user with the computer environment presented before them. An instance of this is the ubiquitous mouse and keyboard that are part of every standard PC. These tools are extremely versatile and useful for interacting with a 2D graphical user interface (GUI) but are not sufficient for more sophisticated immersive 3D interfaces. Auld (1995) discusses the evolution of systems interfaces over the past twenty years. Initially there was the 1D C-prompt of the DOS interface: C:>. Then came the 2D GUI's popularised by the Apple Mac and Windows software. These interfaces are littered with icons conveying information to the user. But most recently the emergence of 3D virtual interfaces has been realised. These interfaces use the 3D graphics capabilities of VRML browsers on the Internet along with associated features such as spatial navigation metaphors. The mouse and keyboard were never designed for use in complex 3D virtual environments. They evolved alongside the emergence of the 2D desktop metaphor. That metaphor while still immensely popular is also widely recognised as being inadequate to deal with the overwhelming volume of information that is now available (partly because it was never intended for this use) (Dieberger, 1995). In VE's, clearly the metaphor used is quite idiosyncratic. This is compounded by the navigational flexibility offered up by VR. Such freedom serves only to overwhelm the functionality of the mouse and keyboard thereby leading to non-intuitive strategies by the user to circumvent these limitations. The result is an intellectual experience that fails to capitalise on the unique and powerful educational affordances that VR provides. These inadequacies can be overcome of course. Kalawsky (1996) suggests that the use of an input device that can exhibit at least six degrees of freedom is required. Such devices include:

- direct manipulation - pick and place
- gestural - hand and body movement
- navigational speech input

- eye control

However until such devices are more widely adopted for educational research into VR, the status quo will remain.

A usable interface should be both intuitive and easy to use. The usability of an interface is regarded differently depending on the experience of the user, their expectations of its functionality and the information expressed through it. Regarding the VE's used in this thesis, several interface issues did arise that were unanticipated. The interface evolves through an iterative process of being designed and evaluated followed by further modifications from the outcome of such evaluations. The motivation for this cycle is an increasing appreciation of the requirements and experience of the users. Assumptions made about the experience and knowledge of the user are often too optimistic. In these cases the outcome of evaluations leads to redesign and modification. Additionally, the requirements of the courseware can also shape the interface.

4.7 Chapter summary

Virtual environments provide the ideal context for bringing together the themes so far described in this thesis. Through the experiential, immersive and interactive presentation of information they challenge traditional ways of knowing and present opportunities for creative learning. Desktop virtual environments facilitate this by making the technology more affordable and usable by educational institutions. The key issue is the extent to which desktop VR can maintain some of the pedagogic advantages of more immersive virtual environments. Clearly they offer huge potential in taking the fundamental elements of effective learning as outlined by the eclectic approach and transforming them through the power of the technology. The challenge for educators is to realise this potential.

5.

Learning in Desktop Virtual Environments

This chapter brings together the principal findings from the literature reviews and proposes a framework for learning with desktop virtual environments. The findings are summarised and consolidated into specific themes that guide the experimental research described in later chapters. Predictions based on the framework are described.

5.1 Themes from the literature

5.1.1 Eclectic approach to learning and assessment

Chapter two described an approach to learning based on pragmatism and effectiveness in the classroom rather than idealised views of the world. This led to the development of ten suggestions for learning that could form the basis for the design of any pedagogical environment. A clear pedagogical framework is a central part of designing a virtual learning environment since it is within this context that all other elements must be developed. Furthermore the affordances of virtual environments for spatial information extend to the provision of non-spatial information. Research in previous chapters outlined the ways VE's can help reconstruct information so that it is more accessible for learning. This is achieved through reifying abstract ideas, transducing information from other modalities, providing alternative conceptual perspectives and using the flexibility to make connections between concepts more apparent. This eclectic approach is as yet untested in a virtual environment though it is hypothesised that a VE could effectively accommodate many of its elements.

5.1.2 Spatial knowledge

The review of spatial cognition outlined the main aspects of spatial knowledge that might interact with learning in a virtual environment. Spatial knowledge is an essential component of learning in virtual environments given the way in which they present such information. Of most interest is the acquisition of spatial knowledge along with navigation issues. Equally important are factors concerning the mnemonic effects of spatial information for memorising and acquiring other knowledge, known as the spatialisation of information. If the spatial information of geological features is conjointly presented with semantic information then memory for both may be facilitated over separate presentation of these features. This would represent an important pedagogical element of any geology field-course. The key question is whether a virtual environment further enhances the facilitatory effects of conjointly presented spatial and semantic information.

5.1.3 Affordance of spatial knowledge acquisition by virtual environments

The review of virtual environments examines the degree to which the technology affords the inclusion both of an eclectic learning approach and spatial information. Many studies point towards the unique characteristics of virtual environments for facilitating the acquisition of spatial knowledge. These factors are often used by researchers to define what is unique about virtual environments and in particular what enables them to become powerful learning tools. Thus a challenge for the thesis is to show how this also applies to desktop virtual environments, and how they can deliver useful affordances for acquiring spatial information over those conferred by regular courseware. There are several reasons why this should be the case. These include the three-dimensional spatial extent of the environment, the ability to navigate through the virtual environment in a first-person mode, and the way virtual environments allow for the seamless inclusion of VENA's. The affordances for spatial information provided by virtual environments are important since they are part of what defines their pedagogical role.

5.1.4 Role of individual differences

Individual differences are an important issue where the design of virtual learning environments is concerned. Of most interest is the degree to which VE's might support differences in spatial ability. Similarly, given the different structural characteristics of information in a VE, the way individuals approach these structures is also of interest. Some researchers claim that these differences in approach to information structure may interact with differences in spatial ability. If this is the case then the manner in which these styles interact should also be investigated. The general aims of this theme is to understand how these cognitive differences, along with differences in experience and motivation might interact with a virtual environment. From this one might be somewhat closer to developing a virtual learning environment that is responsive to the cognitive and usability requirements of the individual.

5.1.5 Usability issues with virtual reality research

Without a well-designed interface, users are too confused, irritated or both to learn from it. The issue of good usability was originally a primary objective of the VLDTK project. There the twin goals of good educational and usability evaluation were assigned equal significance. Though the thesis is focused on pedagogical issues of virtual environments, no discussion would be meaningful without incorporating usability. The main sources of usability information are qualitative data from questionnaires, individual cognitive walk-through's of the courseware, and data-logs. All are valuable sources of information and have a direct influence on the way the interface evolves. Evidence of this is provided at the outset of each experiment chapter where the changes implemented to the user interface since the previous evaluation are described. Most importantly however these two issues of usability and pedagogy impinge upon each other at every level in that a more usable interface is likely to lead to improved pedagogical performance.

Overall these themes form the principal strands of thought running throughout the thesis. On the one hand they may be viewed as a disparate collection of ideas that bear little relationship to each other. On the other hand they may be viewed as a closely entwined set of themes that form the basis of an approach to learning in virtual environments. The relationship between these themes is described as a framework for optimal learning with virtual environments.

5.2 A framework for learning with desktop virtual environments

As described in previous chapters, the virtual environments of the present research differ in important ways from both a real classroom and other types of virtual learning environments. The absence of an empirical model for learning with desktop virtual environments is additional motivation for attempting to present one. A significant amount of psychological research in virtual environments focuses on the evaluation of certain psychological factors to the detriment of others. While important, this type of research is not sufficient for developing a characterisation of what happens when an individual tries to learn through virtual environments. What is also required is some type of framework with which to bring these strands together. Thus, in the present research the aim is to present a description of just such a framework for a specific type of virtual environment.

5.2.1 General description

In the previous section several themes from the literature reviews were identified and elaborated upon as being important to learning in a virtual environment. Since these themes are somewhat present in any virtual environment, it may also be the case that there is a degree of synthesis between them. Figure 5-1 presents a top-down illustration of how these themes might interact while learning with desktop virtual environments.

This relationship is based on both the core and interdependent properties of the themes. These interdependent properties are the glue by which the themes can work together. Each theme is necessarily interdependent for optimal learning to occur. The framework describes three main components: desktop virtual environments, an eclectic approach to learning and spatial

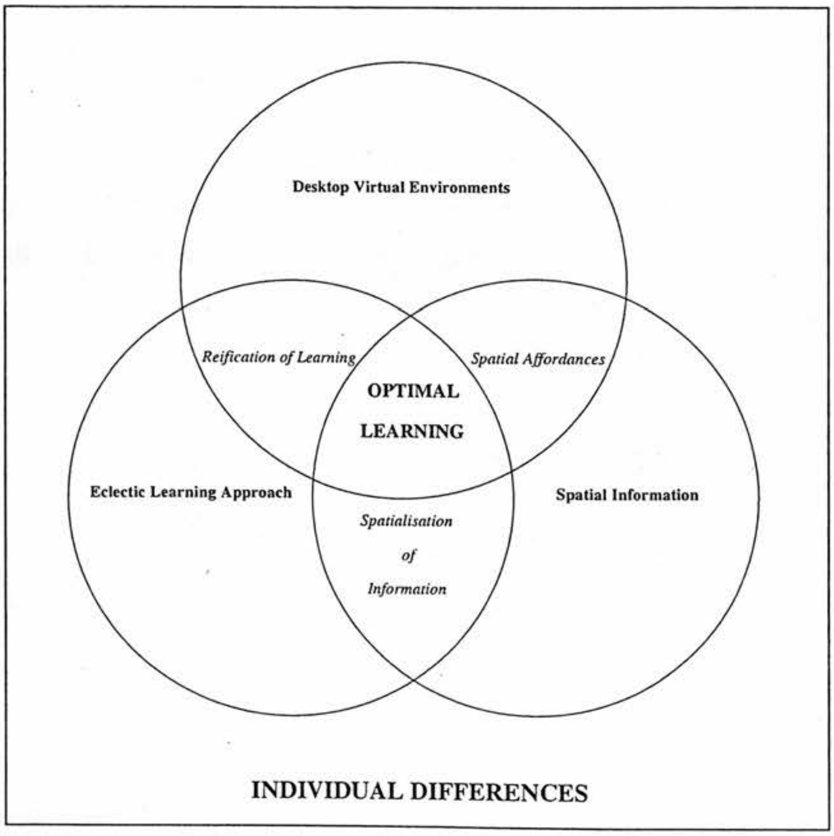

Figure 5-1: Illustration of the elements in the framework for learning

information. However the dynamics of the framework reside in the relationships between these themes through the mechanisms of interdependence: spatial affordance, spatialisation of information and the reification of learning. These mechanisms are the means by which the three themes may come together to produce enhancements in the learning process.

5.2.2 Research hypotheses

5.2.2.1 Spatial affordance

Information presented in a 3D virtual environment is not useful unless it can be structured through the incorporation of navigational awareness. Navigational and orientation awareness allow the user to efficiently retrieve information from an environment. In a VE, navigational aids are especially important for serving this need. Virtual environments are also particularly suited to seamlessly incorporating such navigation features into their structure. This correspondence between virtual environments and VENA's is what is meant by the spatial affordance of virtual environments.

Use of navigation aids in any type of environment has been shown to benefit the acquisition of spatial information. However the additional spatial affordances provided by virtual environments imply that VENA's would benefit learning of spatial information from virtual environments to a greater degree than multimedia environments. Furthermore the nature of the spatial knowledge acquired is expected to be somewhat different to that found from navigation in real environments. In particular a strong degree of landmark-based knowledge is expected to be found among virtual environment individuals but not learners in multimedia or control environments. This is due to the greater anchorage of the geological features in the virtual environments whereas for other groups this is not so. Movement through the VE is on a feature by feature basis. This means that each location the user moves to is based on those geological features that are located there. Thus each location represents one or mode geological features. This method of navigation was imposed by the original development of the virtual environment. Though this is also the case for other groups, the virtual environment anchors this movement with the geographical location of the feature. Similarly it is expected that the type of survey knowledge acquired in each case will differ. For multimedia learners the type of survey knowledge acquired will be more 'geo-centred'. These learners would therefore be better able to give their spatial location through cardinal direction points than as ego-centric coordinates relating to themselves. In contrast, virtual environment learners should display equal amounts of ego- and geo-centric knowledge given their navigation contributes to both primary and secondary survey knowledge (Presson and Hazelrigg, 1994). Route knowledge is not expected to differ between groups given that the same order of locations will be presented.

5.2.2.2 Spatialsation of information

Several accounts of information synthesis between spatial and non-spatial information suggest it improves retention and understanding of the target information. Thus if information is presented in the structured but flexible manner suggested by the eclectic approach, this should result in greater understanding of the information. The most flexible mechanism for accommodating this presentation of information is a virtual environment. Thus, it is expected that enhancement should be more effective with VE's given its spatial extent which favours the inclusion of spatial navigation aids.

5.2.2.3 Reification of learning

To reify means to regard something abstract as real or material. The reification of learning refers to the way in which the learning experience is transformed in a virtual environment through the interaction with information in unique and intuitive ways. Information at many different levels of scale, abstraction and complexity can be manipulated, transformed and experienced in ways that transcend those possible in a real classroom or multimedia environment. Thus desktop virtual environments bring to the eclectic learning approach a powerful tool with which to lever value from the information. Similarly the eclectic approach contributes by proposing a set of principles that are uniquely suited to the additional flexibility presented by virtual environments. It is expected that the enhancement to learning that such principles bring would be greater than the absence of such principles or indeed with a non-virtual environment.

5.2.2.4 Individual differences

Individual differences are expected to play a major role throughout. This is due to a recognition that individual differences are relevant for every component of the framework including its interdependence mechanisms.

- Spatial ability

It might be expected that high-spatial subjects should benefit more from learning in virtual environments due to the greater emphasis placed on visualisation. The converse of this may also be true since the spatial factors of a virtual environment might provide additional cognitive support for the low-spatial individuals. In contrast the multimedia environment would not provide the same level of spatial support and thus might be expected to benefit high-spatial subjects more. Thus, very little difference between high- and low-spatial subjects is hypothesised for virtual environments, but with low-spatial subjects being outperformed in multimedia environments. Non-spatial tests are not expected to yield any difference based on spatial ability.

- Learning style

Holist learners should be more suited to the virtual environment since it provides more degrees-of-freedom for exploring the information and thus would suit their top-down global learning styles. Serialist learners by contrast would be more attracted to the structured multimedia versions of the field-course, and would therefore be expected to perform better in such environments.

- Prior knowledge

Apart from cognitive style, another important feature of individual differences is prior experience. This could vary from prior experience of the learning material to the degree of familiarity with the technology itself. At best one can only attempt to control for such differences.

5.2.2.5 Usability

Usability plays a very significant role in the research. The more usable the interface and its associated technology are, the more likely it is that real and meaningful learning will arise from it. Conversely a poorly designed or unusable interface will only serve to irritate users, leaving little motivation to learn the target material.

5.2.3 Optimal learning

Ultimately it is the synergy produced when all elements of the framework are working together that should enhance the learning experience for the individual. An appropriate learning approach is a fundamental starting point for an effective learning environment. The principles of the eclectic approach provide the basis for flexible goal-directed learning. Through the spatialisation of information, these learning principles are integrated with spatial representations that provide an added means with which an individual may acquire the content. In a virtual environment, the effects of eclectic learning and spatial information are magnified through the reification of learning and the affordances of virtual environments. A virtual environment provides a tool with which to prise open information in ways that were not possible before. It is also uniquely suited to seamlessly affording spatial information. This in turn enhances navigational awareness within the environment allowing for information to be more easily stored and located in more intuitive ways than before.

What makes this description of learning with virtual environments particularly unique is the way that it integrates individual differences at every level. Indeed all other components and mechanisms are subsumed by the importance of individual differences. These differences include cognitive style, the role of prior knowledge, differences in interface usage and motivational differences that individuals will bring to the learning situation. The importance attributed to individual differences in this framework implies that it must ultimately be flexible enough to cope with them.

5.3 Chapter summary

The themes introduced previously are brought together in this chapter to provide a theoretical description of the components and interactions of learning with a virtual environment. Three components: desktop VR, spatial information and an eclectic pedagogic framework interact with three interdependency mechanisms: spatialisation of information, reification of learning and spatial affordance. It is suggested that optimal learning relies on all elements contributing effectively. This framework represents an effort to develop a pedagogic structure specifically for virtual environments. However on another level it is an extension of the more general eclectic approach to learning and the principles for learning suggested by it. Thus the main objectives of this thesis come together in this chapter: to develop pragmatic approaches for learning in real world environments and attempt to extend their applicability to VR. The challenge for the rest of the thesis is to translate this theory into practice.

6.

Pilot Studies

This chapter describes the process of consultation to discover the requirements for a virtual geology field-course. This was an extensive exercise that spanned several months and indeed was an ongoing part of the Virtual Laboratory Developer's Toolkit (VLDTK) project. The first two sections describe how this exercise was carried out. This includes extensive consultation with educationalists, participation on actual field-trips, student interviews and the design and distribution of a questionnaire. This user-needs assessment was in preparation for the design of the courseware that would be built. The third section describes the first virtual geology environment. This was modeled on the Scottish coastal area of Siccar Point.

6.1 The consultation process

A significant requirement for a virtual field-course is to train demonstrators and students on how to get the most benefit out of a geology field excursion. The first step is to carry out an assessment of the requirements and expectations from both educationalists and students. In this section, the consultation process with the educationalists is described.

The VLDTK project was intended to provide tools to enable teachers and students experience virtual field excursions and carry out virtual field-work. From meetings with the Geology department, several requirements emerged defining the basis on which any virtual field-trip should be designed. These requirements are based around several questions:

- Where is it?

When geology students embark on a field-course, knowledge of both their coordinate location and that of the feature they are investigating is paramount. This information can enrich understanding of how certain geological features in the local environment were formed. Many spatial navigation tools were proposed by the Geologists to address this issue. Location maps and terrain models that zoom in on the site of the excursion were proposed. Ideally what was required was an ability to zoom in from the continent scale to the site scale (10,000 km, 1,000 km, 100 km, 10 km, 1 km) preferably smoothly but at least incrementally. Additionally several more specific methods were suggested:

1) A generic method to generate maps with coastlines, lakes, rivers, roads and places
2) Overlays of maps with shaded relief data
3) Provision of Ordnance Survey maps up to 1:10000 scale

- What does it look like?

Most virtual field excursions include a locality photograph with an accompanying description of the geological features found in that area. However it is difficult to relate the locality photograph to the excursion, and the wordy text descriptions distract from concentrating on the key features of the photograph. To improve on this, the geologists proposed:

- A navigation system that relates a photograph to its point on the trail
- An orientation system that shows which way the observer is looking
- A way to select key points on the photograph for further analysis or zooming in

- What does it mean?

One outcome of a field excursion is a better understanding of a sequence of events. For example, the Siccar Point excursion is related to the closure of the Lapetus Ocean and establishment of a desert environment periodically covered by ocean spreading from the south-west. In normal field excursions these events are illustrated with cartoons. In any virtual field-trip one would need to include:

- Plate tectonic reconstructions
- Cartoon production and morphing methods

The macro-analysis of geology fieldwork described above was also supplemented with requirements on a more specific level.

6.1.1 Context setting

Several activities were identified for potential development in a virtual environment. One of these was the introductory talk given at the beginning of a field trip. This introduces students to the geological history of the locality and involves having them imagine what the area might have looked like under different climactic and geographical conditions. Such a context setting exercise could be reproduced in a virtual environment. One possibility would be to have a series of animated cartoons introducing the student to the geological history of the location.

6.1.2 Social factors

On a field-trip, students participate in lively discussion concerning aspects of the geological environment. Often the students are provided evidence of complex or unusual geological formations. They are then required to work together to discover the processes that could have contributed to those formations. This could be in a virtual field-trip. One proposal might be to establish a FAQ's (frequently asked questions) database or even an internal 'bulletin-board' for sharing information and exchanging ideas.

6.1.3 Note-taking

The student notebook is like a diary of the student's activities during the field-trip. It supplements the information on an accompanying map. These descriptions are brief paragraphs containing the essential information associated with each feature. Note-taking features could be built into any future virtual field-trip adding a valuable interactive component to the courseware.

6.1.4 Map reading / map making

Closely associated with the notebooks are student maps. Students must accurately represent and predict the location of geological structures in 3D space. The practical abilities of neat and accurate draughtsmanship, plausibility, supplementation of the map with notebook information on the strata and their contacts are what is assessed. Unfortunately no guidelines are available on the proper production of maps. Quite often improper use is made of the symbols included on the map. One proposal therefore would be to include a map-making tutorial as part of a virtual field-course.

6.1.5 Demonstrators

Demonstrators are guides that accompany small groups of students on a field-trip. They describe the geology of a locality and answer queries from the students. The value of a virtual field-course for demonstrators lies in preparing them for a real field excursion. This could include introducing demonstrators to a location and the important geological features associated with it. This would avoid inconsistencies between demonstrators and lead to more reliable advice and information.

6.2 User-needs analysis

One main outcome of the consultation exercise was to carry out an extensive user-needs analysis. The objectives were to discover the types of activities and knowledge that the students and demonstrators engaged in and attempt a componential analysis of the information. This was required both for the design of the courseware and the appropriate evaluation measures. Another element was to discover students' attitudes and opinions on the real and virtual field-courses. These objectives were achieved in two ways. The first was to accompany students on a one-day geology field-excursion to Barn's Ness, along the Scottish east coast where they would be observed and interviewed. These interviews supplemented a questionnaire distributed to the students. In the sections below this user-needs exercise is described.

6.2.1 The Barn's Ness field-trip

The field excursion began when 80 students and demonstrators left Edinburgh for the 40 minute bus ride to Barn's Ness. While travelling the students were provided with a work sheet for completion during the field-trip. On arrival a demonstrator spoke of the geological importance of the site and set the context for the excursion. This lasted about 20 minutes after which the students split into six groups of between 10 and 20 students.

The demonstrators had an important effect in shaping the dynamic of each group. They would lead the students to an area of geological interest and ask some general questions concerning the features. This was followed by exploratory investigation by students. Eventually the students returned to their groups and the demonstrator sought suggestions to the questions that had earlier been posed. This continued until someone gave the correct interpretation or the demonstrator provided clues. Use of multiple senses to acquire more information was encouraged.

Each demonstrator had a different style of teaching. In one group the demonstrator did most of the talking. This was partly because there were more students to deal with. It may also have been because the demonstrator was more experienced. In other groups student participation was more prevalent. Demonstrators also differed in their background knowledge of the location. The students felt that some demonstrators were not sufficiently experienced and sometimes did not know much more than the students did. A final difference between demonstrators was the influence of their expertise and interests on their teaching style. Thus one might treat geological phenomena as fossilised objects that could yield information through a history of the life-forms that inhabited the area. Another regarded rocks as part of a larger geological picture. Thus demonstrators brought different ways of approaching and interpreting information that may also have influenced the students' interpretations.

Students were constantly introduced to new terms. They discovered the causes of phenomena through observation, description and interpretation. Sometimes this was elaborated into description at the macro and micro level followed by consolidation of these two levels of description. Prior knowledge also played an important role in helping the students interpret what they found on the sites. One demonstrator referred to a laboratory class that she had given the previous week that was directly related to the field-trip. Collaborative working was also an integral part of the field excursion. Students clustered together in small groups though they were also encouraged to wander off on their own to explore the structures in an area. Several students preferred working alone because they felt one might overlook small but important details while in a group. Collaboration was also evident on the bus back to the university when students worked in small groups on a short evaluation test.

The students were given work sheets at the beginning of the field-trip. They contained a map of the area on one side with a series of objectives for the excursion. The other side of the sheet included a Graphic Log into which students were advised to "write descriptions beside the units, add sketches and on the graphs construct a relative sea-level curve consistent with your log". Most students came equipped with a notebook into which they took notes on the points that the demonstrator made to the students. These notes were interspersed with sketches of relevant geological features. Students mentioned that sketching helped to develop an understanding of a structure on a macro level before moving in closer to inspect it in detail. Sketching was thus an effective way of making the students think about the structure and topology of a feature, bringing the qualities of its shape and form into focus. This provided valuable information about those processes that had led to its formation. Sketching was regarded as a more accurate means of describing something like a fossil than a photograph. Colours were also important and were frequently used as clues to the past behaviour of the rocks.

A large part of the day was spent speaking to students about their attitudes to the effectiveness of field excursions as educational resources. The vast majority thought the field-trip was important since it gave them first-hand experience of information they would have read about or heard in lectures. Field-trips brought previously disparate chunks of information together into a single, comprehensible whole. They admitted however that little of what they had experienced could be directly translated into exam answers.

According to students, it was the process of inspecting rocks, noticing the variation in colour, the granularity of appearance and the texture of the surface that was so unique to field-trips. They were doubtful that these elements could be replicated on a computer though they believed computers were relevant. One student suggested using a computer to visit an excursion site before visiting it in reality since students typically received little background information on the sites they visited. Demonstrators were also keen on this idea. They argued that students expected them to be familiar with the idiosyncratic features of a site. However due to staff pressures, demonstrators were given little advance information about the site that they would be visiting. Thus even if the demonstrator was knowledgeable, when applying it for the first time to an unfamiliar site they were often unsure of their interpretations. The students noticed this lack of confidence.

Conclusions

Participation on the field trip proved valuable for learning about the activities of the students and demonstrators. Most interesting was the thoroughly interactive and investigative teaching style adopted by most of the teachers. This was similar to that advocated by the constructivist learning perspective. However, this was not without its flaws. Most apparent was the lack of specific achievable learning objectives apart from general ones to gain a better understanding on the complete geology of the location. Thus, the field-trip lacked a coherent learning structure compounded by inconsistency in teaching styles between demonstrators. One striking component was the collaborative style of working which included rich exchanges between students. However this did not suit everybody with many students opting to work alone. This highlights the importance of recognising the individuality of students' preferred learning styles. The excursion was most effective at stimulating interest in the subject matter. Less certain was the amount of transferable knowledge that students acquired. Instead, previous knowledge was consolidated. These experiences were likely to have a significant influence on existing knowledge structures and in that sense enrich the knowledge that students already possessed.

6.2.2 Questionnaire report

The user-needs analysis included a questionnaire distributed to all students on the return journey after the field-course. Of 140 questionnaires distributed, 102 were returned. An example of the questionnaire is given in Appendix F.

6.2.2.1 Educational content of the field-trip

The objectives of the field-trip were fully understood by 88% of the students. The range of objectives fell into several categories consisting of:

- observation and description of the geology of the surrounding landscape
- the need to consolidate information from lectures
- to correctly draw maps and write descriptions of the structures

All students suggested that more information should be made available both before and after the field-trip. The main purpose of this was to provide an introduction to the locality and set the features there in some kind of context. This reinforces the view that the information taught on field-trips was unconnected with other information from the lectures. Several suggestions to improve this included:

- briefing staff members before trips to ensure consistency of information
- stating general aims and objectives more clearly and accurately

Students were also unhappy with the size of the groups. Large groups were described as the main hindrance to learning mainly because they preclude less-able students from getting the attention they need. When asked to describe the role of the demonstrator, answers clustered around:

- providing help and advice to students
- describing and emphasising important features of the site
- answering questions and promoting discussion
- helping to structure the students' ideas
- maintaining enthusiasm and interest among the group

6.2.2.2 Effectiveness of the field-trip as a teaching and learning resource

This section of the questionnaire was concerned with discovering what learning occurred on the field excursions. Most of the students (over 60%) stated they regularly received feedback on their work. Sources of this feedback included:

- exam and assessment results
- other field-trips where previous trips are used as a reference
- questionnaire results
- Internet
- lectures / practical demonstrations

Similarly over half the students (54%) reported that the feedback they received had a positive influence on the quality of their work. However 34% reported that feedback had no influence.

The questionnaire also dealt with the collaborative elements of the field-trip. Results overwhelmingly supported collaborative working. The reasons for this fell into two main categories. First there were those who believed that collaborative working contributes to the generation and pooling of ideas and helps individual students to build upon their own ideas. This also provides a wider perspective on the material and makes it open to different opinions. Furthermore, many students noted that when ideas were pooled, the conclusions reached tended to be more accurate than those that might have been made if working individually. Secondly, collaborative working encourages discussion and debate of current issues. Thus it compelled students to consider the information more carefully when in the glare of the group before they made comment on it or shared their ideas. This led to group cooperation and taught the students important skills in learning how to work together effectively. From this many other benefits arose such as increased enthusiasm and stimulation of interest.

However, students also noted the potential problems of group working by referring to the sometimes negative elements of group dynamics. Quite often individuals adopted dominant and passive roles. For the latter group this would retard their ability to learn effectively with the group placing them at more of a disadvantage than if they were alone. This is summarised by one student: "Cocky students tend to dominate groups thus overshadowing less confident students". Certainly this is a point worth considering when so much of the work on a field-trip centres around groups.

6.2.2.3 Attitude to technology

This section represented the other main focus for the questionnaire: to assess student attitudes to the introduction of information technology to fieldwork. Over 50% of all students spent up to three hours per week using email and Internet. Regarding virtual reality, 16.7% had used it at some point. Most of the students felt that technology was highly relevant. Over 60% of students regarded VR and multimedia technologies to be highly relevant for geology field-trips. Most of the students (over 66%) responded that they would be willing to incorporate computer technology of this sort into the field excursions. Students were also asked to suggest applications for the different technologies on a virtual geology field-course. The range and foresight of some answers make for interesting reading. Most notable are the uses of VR:

- to show the stages in the formation of the landscape
- provide background and simulations of past environments
- to show the layering of rock
- to visit locations that are inaccessible

Multimedia was given the most comprehensive coverage after VR with the list of applications quite varied possibly reflecting the wide variety of technologies emerging under this generic term. Some applications suggested by students included:

- photos of key features
- for highlighting relevant features
- illustrating present structures
- small scale objects

Students were then offered a hypothetical choice between a real field-excursion and a computerised version and asked to choose one. Female respondents were less inclined than males to use a computerised version of the field-trip (90.5% of all females versus 73.3% of all males). Additionally, more males would choose the computerised version only (11.7%) than the females (9.5%). However there was overwhelming preference among both males and females to choose the real field-trip (80.4%). Additionally only males suggested that they would be willing to combine both the real and virtual field-trip (8.3%).

6.2.2.4 Suggestions for improvement

Students generally wanted the provision of more information before a trip and more experienced staff. Several students suggested the possibility of shorter but more intensive half-day trips, or alternatively, daylong trips interspersed with a series of short rest periods. Students were more concerned about visualising structures that were normally unseen. Again structure and process were suggested as the main uses of any computer-based approach to learning geology. The provision of background geological histories while viewing certain sites and associated structures was also mentioned. The use of courseware for coaching and testing student knowledge was another suggested application. The WWW was mentioned as providing an opportunity to view information about the location and allowing students to see other sites from around the world. This could incorporate photos of features, animations of erosion through the ages and follow-up exercises. This would be especially useful for areas that are inaccessible.

6.2.2.5 Issues regarding the questionnaire

Students highlighted a few problems with the questionnaire. These included:

- being difficult to understand since students were not fully aware of its context
- unfamiliarity of students with certain types of technology led to inconsistent answers
- lack of sufficient space to properly answer questions

More positively several students commented that the questionnaire gave students an opportunity to voice their concerns about the course and the quality of teaching they felt they were receiving. Detailed results from the questionnaire are given in Appendix A.

Conclusions

Overall the questionnaire proved to be extremely useful. Several themes emerged as providing the basis upon which any virtual field-trip should be designed. First, it was agreed that additional background information should be provided on the field-trip. The purpose of the information is to set the context of the field-trip for the students. Research from cognitive psychology has shown that learners are better able to attend to and acquire new information when it can be related to existing knowledge. Another major theme was the importance of the social. Students work and learn together almost continuously and this is something that they value as part of the field-work experience. Finally, many students displayed a high degree of knowledge and usage of the Internet and computers. This familiarity with technology appeared to bring recognition of its importance for enhancing the field-work experience. Over two-thirds of the students were willing to incorporate some form of technology into the teaching and learning process.

6.3 Outcomes of the user-needs analysis

6.3.1 Description of skills

The data from both the consultation process with educationalists and the questionnaire and interview data of the geology students revealed the following list of commonly taught skills:

- Inferring processes from the structure of the rocks

Most of the trip consists of making interpretations and hypotheses based on available evidence from the surrounding structures and on the ability to bring prior learning to the fore. Though the specific content of the tasks might vary, the actual tasks themselves are very much about recording, recognising, studying and seeing. They are all activities related to observation and description.

- Consolidation of information and its application in the field

Most of the activities require the students to apply a certain amount of prior learning to the field-trip. This could make it possible for them to associate the field-trip experience with prior knowledge. Therefore the opportunity to access background information on different objects of interest while on the virtual field-trip would serve to elaborate this knowledge.

- Description of micro and macro processes

Describing a landscape in geology requires examining it from many different perspectives and scales. A key skill is to examine a locality on different scales and consolidate them into a narrative of its geological history. This is something that could be captured in a virtual field-trip. In particular one might develop a tool that could zoom in and out of the details of a site as required.

- Opportunity to take notes and sketches

Both these activities force the student to reflect on the feature being described. The sketching process requires the student to pick out certain details that might otherwise have gone unnoticed. The obvious application would be to provide multi-perspectival views of different objects that are to be sketched. Providing the user with the flexibility to control the viewpoint of the object and to zoom in and out from it would improve their knowledge of the object.

- Demonstrating contextual knowledge of a location

Rather than relying on lectures and laboratory practicals, this skill encompasses the ability to examine the features in the context of the surrounding area. This is because the interpretations drawn from certain features could be quite different depending on the surrounding geology.

- Knowledge of terms, structures and processes

This consists of didactic knowledge about names of processes, structures and an understanding of the classification of that information. It is an understanding of the language that geologists use. New names for structures and processes are frequently mentioned on a field-trip and an ability to quickly absorb and understand these terms is an important skill.

- Demonstration of social skills

Social interaction plays a significant part in the smooth running of the field-trip. An ability to interact and function as both a group and an individual within a group are two skills that are very relevant for ensuring successful learning experiences.

- Role of the demonstrator

The demonstrator must be one who is prepared to work through problems with the students and can answer the questions directly. This highlights their importance to the teaching process and implies a need to incorporate a similar approach on the computer. If the skills identified above are to be taught through the computer then some effort must be made to approach the teaching process from the demonstrator's perspective. The role of the demonstrator emphasises the need to focus on educating and not simply simulating or visualising. Placing the student in a kind of learning cycle that passes through instruction, simulation, investigation, assessment and feedback is what is required.

6.3.2 Constraining educational needs with technology

The previous section described the main educational tasks that students engage in during a typical geology field-trip. The challenge is to match these educational requirements with the principal types of virtual environment technology used. Thus the first step was to choose the appropriate type of technology and then to attempt to meet as many requirements as possible.

The remit of the VLDTK project regarding the technology was that it had to deliver courseware in a way that was sophisticated and professional enough to be used by both educationlists and students. Other considerations included the time to develop the courseware and the budget for acquiring the appropriate technology. In addition human resources were at a premium. With a geology field-trip the principal type of information was the visualisation of detailed geological structures. Thus, any technology would have to produce high quality photographic images of these features. The most suitable VE's for including such realism are image-based virtual environments.

The challenge was to find a tool that would combine the software for processing the captured images, with software for incorporating such images into a virtual environment. Furthermore, other technology was required for including content with the virtual environment. These requirements narrowed the field to a handful of available packages of which the Reality Studio software bundle was the most suitable. This package is described in chapter 4. Reality Studio contained many features that made it a very suitable candidate for developing desktop virtual environments in Geology. The main features were:

- it produced image-based virtual environments
- it could process images and develop immersive, interactive virtual environments
- it was deliverable across the Internet though flexible plug-in programs
- it contained a usable GUI interface

The choice of Reality Studio meant that this software was used for the research in this thesis. This had a significant impact on shaping educational issues. It is possible to incorporate video and audio clips, VRML models, three-dimensional image objects (IMOB´s), animated images, scripted movies, many interactive features and text into the virtual environments created by RS. In addition, many more interesting variations are possible when these media are combined in various ways with the interactive components of the software. What was not fully appreciated however were the severe bandwidth constraints that would be imposed by the necessary delivery of this courseware across the Internet. The educational requirements highlighted in the user-needs analysis are described below in relation to how they might be implemented through the technology. Occasionally the technology imposed constraints that necessitated alternate means of providing the requirement.

- Interaction

As much interaction as possible was needed for the virtual field-trip. This implied a virtual environment that allows users to decide where they are to go; the freedom to look about them and explore an area; to choose rocks that they think might be of interest and zoom in on one part of them to examine them in greater detail. The use of an electronic notebook to include notes from on-site exploration would also be important.

- Immersion

The degree of immersion in the geological virtual field-trip was minimal given the type of VR being used. Consequently, the learning potential associated with more immersive VR might not be capitalised upon. Concerning the problems of inefficient demonstrators and incomplete distribution of information on site, the VR package could offer significant advantages but was unlikely to compensate for real field excursions.

- Interface issues

The interface was primarily web-based. The virtual environment was delivered to the user as a window set in a web page. The window displayed the virtual environments and was interactive. This interactivity allows the user to navigate the VE via the *click* and *drag* of a mouse. Furthermore, any other interactive features contained in the VE were accessed either through this method or through the keyboard.

Besides the functionality of the VE, the interface could also incorporate any additional features built into the web part of the interface. Thus, the VE viewer could be incorporated into a framed web page with one framed area elaborating on the information contained in the viewer. These two viewing areas could also be made to *communicate* with each other. Thus elements may be activated in the VE viewer that would trigger actions in the other viewing area. This was important for updating the information in other parts of the web page (e.g. a map) when one navigates to another location in the VE viewer.

- Macro- / micro-scopic visualisation

This was useful for first exploring a new location and helped to set the context for the field-trip. Such techniques could be supplemented with additional contextual information such as current weather conditions or the history of the area and so on. Though the VE viewer included a zooming function, when one did zoom in for a closer view of an object, the image pixilated. Thus, there were no real benefits to be found by zooming into geological features to get a closer look at them. This drawback was compensated for in a number of ways including overlaying higher quality images on selected parts of the panoramic image; using the interactive elements of the VE viewer to reveal increasingly higher resolution images of an object, and finally use of Flashpix images. A disadvantage with any of these mechanisms was the increasing computational overhead due to the size of the high quality images.

- Multi-sensory

Demonstrators were a valued part of the field-trip and performed many functions to help the students learn about the geology in a fun and interesting way. One educational requirement therefore, was to incorporate multimedia presentations of the features in the VE. This would decrease cognitive overload by reducing the need to divide attention between a textual description and the diagram of a feature. Though audio and movie clips were produced it was soon realised that they affected downloading of the VE. This was also the case with VRML models of geological objects. It was therefore not possible to incorporate many of these features into the main virtual environments. Despite this some examples of the video commentaries were included in the Siccar Point version while audio clips continued to be used in the Holyrood Park virtual environments.

- Animation

Animations were used to illustrate some dynamic processes that led to the formation of the geological features. One attempt at this was the development of animated images. These consist of several static images played one after the other very fast to give the impression of smooth motion. Processes of erosion and the transportation of materials could be speeded up in an animation to illustrate how they contributed to the features that are seen today. However, these animations use significant bandwidth for downloading. In addition a bug in the visualisation software meant that any such animations incorporated into the virtual environment played at a ridiculously fast speed. Attempts to slow such animations increased the bandwidth. For these reasons the animated images were not included in the evaluated virtual environments except for the Siccar Point field-trip.

- Multi-perspective visualisation

Multi-perspective models of the field-trip locality would be most beneficial for first year students being introduced to geology. A three-dimensional model allowing the user to strip away layers to see more detail were an important feature not available to the students on a field-trip. One way of doing this would be through the IMOB's described in chapter four. These are objects that allow a two-dimensional image to be mapped onto a three-dimensional object thereby giving the impression that the feature is a three-dimensional solid. IMOB's were not used since they required a sophisticated image-capture studio that was beyond the facilities of the laboratory during the project.

However, multi-perspectival visualisation also refers more generally to providing the learner with multiple views of the same object or area. In this regard, multi-perspectival images of the geological environment were produced using both the images captured at ground level along with aerial photographs of the relevant area. In early versions of the virtual field- courses this information was further supplemented with local ordinance maps. These depicted the geology of the area with three-dimensional computer-generated images. In this sense, the courseware was very effective at producing information from multiple perspectives.

- Transfer of knowledge

The geology field-trips are regarded as self-contained parts of the curriculum. Their educational value lies in giving the students an opportunity to realise what they have learned in lectures through interacting with real geological structures as they are naturally found. No identifiable knowledge that may have been acquired from the experience of the field-trip is evaluated by the educators. An exception to this is the short multiple-choice test given to students as they make their way home from the field excursion. Thus a main task for the evaluation was to quantify knowledge acquired from the field-trip and use it to guide the design of the courseware. Furthermore, to be certain that some knowledge was acquired, a comprehensive evaluation component was designed into the courseware.

- Computer supported collaborative work

The value of collaborative learning and working was highlighted in the user-needs analysis. It would be useful to establish an electronic bulletin-board among the virtual field-work students as a mechanism by which they could share ideas and answer each others queries. From this a body of answers to such queries could be established as a list of FAQ's.

Conclusion

Overall the investigation of the requirements from students and educationalists alike was a fruitful one. It presented them from the point of view of an educationalist attempting to transform the teaching methods through the manner in which information could be presented and experienced. While they welcomed the prospect of technology making geology more interesting, users were confident that it could never supplant the real field-trips. The information relating to the types of activities and the knowledge acquired from the field excursion was described and categorised as much as possible. This led to several educational requirements that would form the basis for the design of the courseware and its content.

In the sections that follow, the wealth of information collected through the user-needs analysis is established with the development of the first virtual geology environment of the thesis. Though designed primarily as a pilot and demonstration model of what was possible, the Siccar Point VE was nonetheless evaluated for both educational and usability features.

6.4 Evaluation of the Siccar Point virtual field-trip

This section documents the evaluation of the Siccar Point virtual field-trip. It describes the courseware and how it was implemented. It also describes the evaluation, the reasons for it and what it set out to achieve. This is followed by a discussion that attempts to bring the results of the different components together. It also discusses what can be learned from the evaluation and makes recommendations for future VE's.

The Siccar Point courseware contains three main sections. An introductory section details the practical aspects of going on a field-trip including the accessibility of the location, the appropriate clothes to bring and the type of weather that can be expected. Following this there are two sections covering the two parts to the trip. The first part is based at Siccar Point. This provides an overview of the location and a feature by feature description of the geological structures. The description consists of images of the geological objects accompanied by a short textual description. The final section of the VE consists of an account of the Pease Bay area. This is structured in a similar way to Siccar Point.

The interface to the VE consists of two frames in a web page [see Appendix G-1 for a screen-shot]. On the left side of the page is a menu list of the entire contents of the VE. On the right side of the page the contents of each item from the menu are displayed. To view a feature the student clicks on the appropriate link from the menu and the corresponding information appears on the right side of the page. This version of the field-course did not use the Reality Studio technology since this was a very early demonstration version and the VE software had not yet been acquired. Thus, this version consisted of wide-angle panoramic images and the functionality of the web-pages to present the information and thus was more multi-media than virtual reality. Nonetheless the evaluation was useful for testing many elements of usability and learning in a computer-based learning environment.

The VE also contains an evaluative component. This consists of a test of general spatial ability, three tasks on the degree of spatial orientation experienced within the VE and a questionnaire. The general purpose of evaluation within the VLDTK project was to determine the efficacy of virtual teaching environments in higher education. This included everything from usability and educational issues to more general evaluations of the technology in different teaching environments. For the Siccar Point VE, this concerned the degree to which the VE provided the student with:

- orientation information for the geology locality and its features
- an introduction to the main geological features
- provision of training in object sketching
- associating classroom learning with real world practice

6.4.1 Method

6.4.1.1 Subject profile

A total of 137 subjects participated in the Siccar Point evaluation (75 males and 62 females). The average age was 18.2 years. The real field-trip takes place over the course of a weekend with each student self-selecting to go either on Saturday or Sunday. The Saturday group was appointed the 'experimental' group (82 subjects) while those students travelling on the Sunday were selected as the 'control' (55 subjects).

6.4.1.2 Design

In this experiment the two subject groups each completed an alternative version of a virtual environment (VE) fieldtrip modeled on that of the real thing. This was completed a few days prior to the real fieldtrip that all students were about to go on. In the VE for the experimental (Saturday) group, a number identified each feature on the menu list. This number relates to a wide-angle colour photo image of the field-trip locality overlaid with the corresponding numbers at the appropriate locations for each feature from the menu. Thus, the location of any feature from the menu list can be identified on the photo image. The control (Sunday) group was not provided with any numbering system though they did see the same photo images as the experimental group. However these were only of limited value since they had no system of identifying each feature with its appropriate location on the photo image.

The experimental group was also shown a sequence of pictures containing features with the appropriate sketch superimposed on it. They were also shown a completed sketch that included all of the appropriate labeling information. The control group received no such training. Finally, both groups received information on plate setting which illustrated how continental drift contributed to the formation of geological structures found at Siccar Point. However for the experimental group an additional animation sequence showing the movement of the continental plates was provided and could be played as often as needed. The control group received no such animation though the same idea was presented using text and static images. Once these viretual environments were completed, all students participated in the real fieldtrip a few days later (overf the course of the weekend). The following week all students completed the evaluation tests associated with the fieldtrip.

6.4.1.3 Methods used

The evaluation began with a test of general spatial ability. This was followed by three specific tests of the spatial knowledge that was acquired from the virtual environment. The questionnaire was presented to students once they completed all of the content material and the spatial tests. Additional measures of evaluation included digital data-logs of the students' progress through the VE and coding of the notes and sketches made by the students on the real field-trip.

- Revised Minnesota Paper Form Board test (RMPFB)

The Revised Minnesota Paper Form Board test (RMPFB) (Likert and Quasha, 1970) is a 64-item paper-and-pencil test of general spatial aptitude (more recent versions are computer based). Each item consists of a figure cut into two or more parts. Five other complete shapes are also displayed. One of these is equivalent to how the target figure would look if all its constituent parts were joined together. The task is to choose the appropriate figure from the five options. The test is timed with twenty minutes allowed for completion of all sixty-four items. If at the end of twenty minutes all the items have not been completed, those not answered are discarded. The total number of correct and incorrect answers is used for scoring purposes. The validity and reliability of this test has been researched. Anastasi reports that "an unusually large number of studies conducted with this test...indicate that it is one of the most valid available instruments for measuring the ability to visualise and manipulate objects in space" (1990).

The RMPFB was chosen as a standard test of general spatial ability. Performance in this test was compared with the orientation tasks so that any discrepancies would be due to the location information of the virtual field-trip and not because of individual differences between subjects on spatial ability.

- Landmark knowledge

The purpose of the spatial tasks was to discover the type of spatial knowledge that the students had acquired on the trip and to see if the VENA's included in the experimental VE affected performance on these tasks. No such modifications were made to the control group. The first orientation task was a test of landmark knowledge. Students were shown an image of Siccar Point that included numbers superimposed on it. This image is identical to one they would have encountered in the VE though for the control group the picture would not have contained numbers. The numbers denote the location of geological features in the VE. A list of features is also provided under the image. The task is to match the features with the appropriate numbers on the map.

- Route knowledge

In this test the students were told to imagine walking from one part of the VE to another. Three pairs of images are presented each of which displays a geological feature from the VE. For each pair, the student must decide which of the two features they would encounter first if taking the route they were asked to imagine.

Survey knowledge

Here, the students estimated the straight line (Euclidean) distance (in metres) between either: themselves standing beside a particular feature and another feature or, between two features

Three statements of each form were presented along with a selection of four distance estimates. Subjects then chose the number that they felt was closest to the true Euclidean distance between the two locations.

Questionnaire

Following the three orientation tasks, a questionnaire was administered consisting of 23 items, 16 for the students while seven items were for educators only. The 16 questions were divided into four sections covering:

- Learning experience
- Usability experience
- Hindrances
- Future improvements

A 'comments' box was also included.

- Data logs

Each student was electronically logged when they began the experiment. The data provided a record of the amount of time the student spent on each file. Usually such files correspond closely to the menu list of features in the VE. This information is useful for detecting the degree of interest a student displayed in each area of the VE.

- Student sketches

On the real field-trip students are required to sketch some features they examined. These sketches were coded to decide if the training in object sketching greatly affected learning.

- Student notes

Students were required to make notes on the features that they examined on the real field-trip. The quality of these notes could provide clues to decide if the VE had any positive learning effect on the students' knowledge.

6.4.2 Results

This section describes the main results from the evaluation. A complete presentation of the results is given in Appendix B.

6.4.2.1 Revised Minnesota Paper Form Board test (RMPFB)

Eighty-two subjects participated from the Saturday group and 55 subjects from the Sunday group. Since the answers were in multiple choice form, the raw data was corrected for guessing. Independent measures t-tests found no significant differences between the Saturday and Sunday groups while [t(135)=-1.23, p=0.221, NS] or males and females [t(135)= -1.76, p=0.081, NS].

6.4.2.2 Spatial knowledge tasks

Landmark knowledge

Seventy-five subjects from the Saturday group and 54 subjects from the Sunday group took this test. The difference in subject numbers between tests reflects both subjects that failed to complete the test and results removed because subjects completed the test improperly. Figure 6-1 illustrates the difference between the two groups across items of the LANDMARK test. It is somewhat smaller for the last four items that refer to the Cove Harbour location. An independent measures t-test found a significant difference between the experimental and control groups for this test [t(127)=6.04, p<0.001], indicating that the experimental group outperformed the control group in terms of demonstrating landmark-based knowledge of the areas.

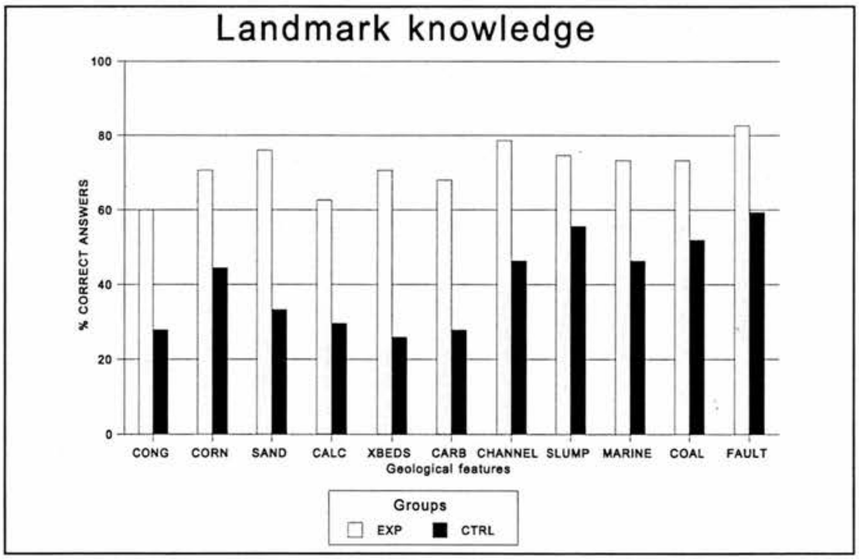

Figure 6-1: Bar chart of the percentage correct answers for items of the LANDMARK test.

Route knowledge

Seventy-four subjects from the Saturday group and 51 subjects from the Sunday group took this test. An independent measures t-test found no significant difference between groups for the ROUTE test [$t(123)=0.29$, $p=0.776$, NS], though there was evidence of ceiling effects.

Survey knowledge

Seventy-one subjects from the Saturday groups and 49 subjects from the Sunday group took this test. As for the ROUTE task, an independent measures t-test found no significant difference between the two groups on the SURVEY task [$t(118)= -0.02$, $p=0.98$, NS].

6.4.2.3 Individual differences and spatial knowledge

Data from the spatial tasks was analysed for individual spatial differences as measured by the RMPFB. Subjects were classified as either high- or low-spatial based on test performance and divided using a median split of the data. Table 6-1 shows the outcome of this re-analysis:

	Experimental		Control	
Test	Hi-Spatial	Lo-Spatial	Hi-Spatial	Lo-Spatial
Landmark	7.9	8.5	3.8	5.0
Route	2.4	2.5	2.4	2.3
Survey	2.9	2.9	2.7	3.1

Table 6-1: Mean scores across the spatial tests split by high- and low-spatial subjects

None of these differences were significant. Despite this, they do indicate some interesting trends in support of the hypotheses. The computer-based environment of the type used by the experimental group enhanced performance on a test of landmark knowledge. This is what would be expected from using navigation features such as the location numbers. Subjects designated as low in spatial ability (lo-spatial) performed better than their hi-spatial counterparts for both the experimental and control groups. These results support the hypothesis of spatially weak students benefiting from computer-based learning.

Performance data for the SURVEY test were more difficult to interpret. While the hi-spatial subjects of the experimental group performed better than control, this trend reversed for the lo-spatial subjects suggesting that the navigation features suited the hi-spatial subjects more. Results for the lo-spatial subjects in the control group show that they performed better than their hi-spatial counterparts. However, there was some design problems with this test.

This analysis shows that the inclusion of spatial aids did differentially affect students' performance. These differences were most evident in the results of the LANDMARK task. The possibility that such spatial aids could be especially beneficial to students that are less spatially sophisticated was an exciting one.

6.4.2.4 Student sketches

Eighty-one subjects from the Saturday group and 62 subjects from the Sunday group completed sketches. An independent measures t-test found no difference between the sketches of the two groups with the mean difference being very small (Saturday mean: 3.51; Sunday mean: 3.48; difference between means: 0.03) and not significant [$t(141)=0.83$, NS].

6.4.2.5 Student notes

Students' notes were included in their Geology 1 Field-trip Assignment sheet. The notes are answers to multiple-choice questions and reflect conceptual knowledge acquired from exploring the geological features on the field-trip. Eighty-one subjects from the Saturday group and 62 from the Sunday group completed the multiple-choice questions. Control groups did slightly better on the assignment sheet than their Experimental counterparts though this difference was quite small [0.16], and an independent measures t-test found it was not significant [$t(141)=-0.39$, NS].

6.4.2.6 Questionnaire

- Learning experience

Many subjects (45%) stated they enjoyed the Siccar Point virtual field-trip while a significant minority remained neutral (35% of Experimental and 31% of Control). This suggested there was potential for improvement. Most of the experimental (62%) and almost half of the control (48%) subjects indicated that they believed the VE was a valuable learning tool. When asked what they thought they were supposed to learn, a selection of answers suggested information on the geology of the locality, along with an emphasis on the relevant orientation information both of the locality itself and the individual features within.

The plate animation was relatively well received with 41% (36% did not know) of students in the experimental group claiming the animation helped to increase understanding of plate- setting. Similarly when asked if they found the sketching exercise valuable, most students (46%, 20% did not answer the question) answered positively.

Most of the students felt the VE did contain a valuable pedagogic component. They also found the VE moderately enjoyable to use. The only negative result was the lack of correspondence between the material contained in the VE and the material covered by students in their course work. This reflects the situation in real world geology excursions.

- Usability experience

A significant minority of both the Experimental and Control students (42% and 37% respectively) were frustrated by the limitations of the VE. Combined with the *satisfaction* data, this suggests that the VE performed without many significant technical problems. Most students (69%) found the information easy to follow. The quality of that information was well regarded with a majority (67%) of students saying that they were either satisfied or very satisfied with the standard. The usability section ended with a question that asked students to identify issues that may have hindered the VE. These included:

- too many static pictures
- too much text
- poor indication of the users' location at the site
- slow down-loading of images
- the interface

The vast majority of students regarded the poor quality of orientation and navigation features as the biggest hindrance to the virtual environment. This emphasised the importance that needed to be given to the provision of better quality spatial information in future versions of the virtual field-course. Lack of spatial information was more of a concern for the Control group (48.3%) than the Experimental group (29%). This was a promising result since it suggested that the inclusion of spatial aids in the Experimental version had reduced anxiety about the lack of spatial information. Furthermore the difficulty students reported with the spatial knowledge tests (see below) made them realise just how little spatial information they had actually acquired and so this became a concern of theirs for a future version of the VE.

Future improvements

The most common improvements suggested included:

- more student interaction
- more navigational aids to improve orientation
- opportunities to ask questions

The most positive aspects of the Siccar Point VE were the:

- use of photographs and explanations
- examples of field- sketches
- detail of certain features

Particularly poor was the:

- lack of any overview map of the site
- difficulty of orientation tests
- lack of adequate navigation / location cues - problems of disorientation
- overuse of the computer for teaching geology

6.4.3 Discussion

6.4.3.1 General analysis

Poor spatial orientation may hinder performance on the other aspects of the field-trip. The Experimental group in the present study had the advantage of associating specific features from the menu list with photo images of the actual site. The degree to which this was an effective means of generating spatial knowledge in those students was measured by the three orientation tasks. The only task to produce a statistical difference was the LANDMARK knowledge test. Thus, associating the feature in the menu list with its location on the photo image of the site results in the generation of LANDMARK spatial knowledge.

This contrasts with the other two spatial tasks where no significant differences were found. One reason performance on these tasks was so poor was possibly due to the spatial layout of the features. The spatial layout of information in the VE was not sufficient to enable survey knowledge to be acquired. Students complained of not having an overview of the locality. Furthermore no scale was provided of the distance between the features. An attempt to incorporate route information into the VE was also neglected. A closer correspondence between the presentation of the features and their relative spatial locations to each other would improve users' survey representations. Problems of disorientation were not helped by the inherent structure of information. One complaint by students was that the VE was disjointed and erratic in its structure. In particular one was required to *jump* from the menu to the location photos or to information on the item itself, before *jumping* back again to the menu. It would appear that this navigational process contributed to the feelings of disorientation and confusion among many students.

One promising trend was the possibility that the spatial aids might be particularly beneficial for less spatially able students. If this proves to be the case in later experiments then the research conducted here could have important remedial implications.

Acquisition of geological knowledge was measured by performance on the plate-setting animation, field-sketching exercise and the multiple-choice questions. Despite no significant differences qualitative data showed that the experimental group found the animation very helpful for learning about the concept of plate setting. This would suggest that there is much potential for a significant non-spatial learning component in the virtual field-trip.

The VE ran without any technical or user difficulties. This was supported by high user satisfaction in the questionnaire. Regarding the design of the virtual environment, students considered the poor orientation on the site as the single biggest hindrance. The experimental group encountered problems with slow downloading of images. Finally, control students were most likely to spend an hour or less whereas their experimental counterparts were evenly divided between spending one and two hours on the VE. This may indicate that if the VE is made more interesting then students will be prepared to spend longer on it.

6.4.3.2 Recommendations

The message from the Siccar Point evaluation was that better quality spatial navigation and orientation needed to be provided. As a first step, several suggestions were made for any future virtual field-trip.

First, a context-setting measure such as an initial zoom-in device could be designed to help the student represent the spatial location of the site in relation to their wider knowledge of the geography of Scotland. This could be accompanied by a map-like overview of the area that would constantly be available to the student as they navigate the environment. Much research has shown that the provision of map-like representations helps develop secondary-level survey knowledge. This is the type of knowledge required for successful orientation by the student. Instantiation of secondary survey knowledge also aids in the development of landmark and route knowledge. Finally, better quality panoramic images of the geological locality increases user control and generates improved orientation in the environment. Future improvement also needs to include the ways in which spatial knowledge is evaluated. Additionally, more direct comparison needs to be incorporated into future evaluations. The effect of increased spatial knowledge in the VE also needs to be examined for its impact on geological knowledge and usability factors VE.

In any future virtual environment, much more use of available technology should be used. Interaction can be applied to many different types of technology and can take many forms. At a basic level it refers to increased amounts of participation in the VE by the student. This is evidenced by the call for more question-and-answer type scenarios in the questionnaire. Another feature is the opportunity to take notes. On the real field-trip the students keep note-books in which they describe the features they encounter. These become records of their experiences. Again a similar feature if incorporated into the VE would greatly increase the realism of it and give the students the chance to make a record that could be combined with the notes they make on the real field-trip. Additionally, if they cannot go on the real thing the notes could act as a substitute record.

Using movie-clips to present different activities and indeed multimedia more generally is urgently needed given the complaints among students about static images. There is much controversy in educational literature about whether animations and multi-media applications more generally actually serve to enhance the educational experience in any meaningful way. Certainly some positive results have been found for their use but they are under specific circumstances with certain type of information. However use of multimedia is justified if it increases interest and enjoyment of the VE. In the present example such factors resulted in a greater willingness to spend more time on the VE that may indirectly improve student learning.

Conclusions

Despite many shortcomings the Siccar Point evaluation generated a significant amount of useful information that may be used to improve the design of future VE's. Critically the incorporation of sufficient navigational aids to generate and maintain orientation within a virtual environment is essential for releasing cognitive resources. These resources can be dedicated to the learning of more important content material.

The VE also needs to become more ambitious. The user should be given more control over the way they learn information. More flexibility in information presentation and more learning by example (such as with the sketching exercise) is important. In goal-directed, structured, environments, these factors are the elements that could help enhance the learning experience in future implementations.

6.5 Chapter summary

This chapter achieves several objectives. First, it sets out the process by which knowledge in the real world must be quantified before suitable courseware may be developed. Secondly, it describes the design, development and evaluation of the first desktop virtual environment. In so doing it highlights the challenges faced by researchers when conducting research with this technology. Finally, the chapter provides initial support for several elements of the framework for learning with VR outlined in the previous chapter. Overall the chapter emphasises the applied nature of the research. It highlights the need to first observe, identify and then quantify the knowledge that is to be taught and evaluated. The outcome of the research with Siccar Point led to changes in the way the virtual environment is both designed and evaluated. The introduction of image-based VR software however, would lead to a very different virtual environment and a whole new set of challenges.

7.

Evaluation of the research themes

The outcome of the Siccar Point evaluation formed the basis upon which further research into learning with a virtual environment could occur. The need for a more accurate evaluation of the potential for learning delivered by desktop virtual environments became the motivation for the experiments described in this chapter.

Four experiments (experiments 2-5) are described. Experiment two was a large-scale experiment that used three-dimensional, image-based, virtual environments to describe the geology of one of Edinburgh's most distinctive natural landmarks: Holyrood Park. The outcome of that experiment shed further light on the themes highlighted in chapter 5. Much was learned from this analysis that allowed more focused research to occur with the Psychology department. Experiments three and four clarified and extended the findings of the first Holyrood Park evaluation. The fifth experiment focused on the synergistic learning effects of combining spatial and non-spatial information. The last three experiments were carried out in collaboration with the university's Psychology Department though they were designed and evaluated personally.

7.1 Experiment 2: evaluation of the first Holyrood Park virtual field excursion

This section documents the first evaluation of the virtual geology field-trip developed using image-based VR technology. Holyrood Park is an area of natural beauty located in the centre of Edinburgh, Scotland's capital city. The park extends to approximately 650 acres and is notable for the remains of an extinct volcano known as Arthur's Seat. The surrounding geological features of the park are directly related to this volcanic influence and indeed are what makes it attractive to geologists. The Holyrood Park field-trip is the first one that undergraduate geology and geo-science students participate in after beginning their courses in the Autumn term. The field-trip usually takes place in early November and consists of a day-long excursion through the park.

7.1.1 Holyrood Park virtual environment

The VE produced for Holyrood Park was a fully interactive, three-dimensional, image-based environment that seamlessly incorporated multimedia information with relevant spatial and pedagogical aids to deliver a completely self-contained learning environment.

The virtual environment contained nine image-based panoramas of the park linked by a system of hot spots. When interacting with the panoramas, the learner used a dedicated tool-bar. This tool-bar included several navigation and visualisation functions. All interaction with the virtual environment was conducted via a 'mouse'. Though the panoramas were of reasonably high resolution they sometimes fell short of the resolution required (e.g. for zooming functions). To compensate, higher resolution images were overlaid on some parts of the panoramas to give a better quality display of selected parts of the park.

Many supplementary elements were added to enhance the experience of visualising the information. These included a 30-second movie file depicting a *fly-over* of Holyrood Park, and a VRML-based virtual environment that replicated the park[1]. The model could be fully explored and included an interactive element where all of the geological features were highlighted using audio labels. These visualisation features added yet another dimension to the general experience of learning in the Holyrood Park virtual environment.

The Holyrood Park VE was also more interactive than its predecessor. One could select images of geological features, use interactive question-and-answer sessions and activate movie and audio clips. The environment was also interactive in the way it responded to the users' desire to explore

1

Both the movie clip and the VRML model of Holyrood Park were designed and developed by other members of the VLDTK team, namely John Blair Fish and Gordon Watson respectively.

those parts of the environment that they felt were relevant.

Although the movie clips of commentary were not developed for the Holyrood park environments, the movie fly-over as already described added a multimedia perspective, as did the VRML model. Audio was the main multimedia component of this VE. Audio clips were used to describe each new location the user visited. When the user clicked on a hot-spot to go to a new location, an audio clip played describing the location and the main geological features of that area. An additional audio clip was developed as an introduction commentary when the user first entered the virtual environment. It described the layout of the virtual environment and instructed the user on how to interact with it.

The virtual environment incorporated several new spatial features. These may be divided into two types: those designed to improve orientation and those designed to aid navigation.

Orientation features:

- Name-to-location feature labels

  Each of the textual descriptors for the geological features was placed at the approximate location in the environment at which those features would be found in the actual park. Thus when one read the labels, information about the spatial location of these features was also conveyed.

- Compass features

  The four cardinal points analogous to a typical compass were superimposed on the panoramic images in the approximate direction to which the points would refer in the actual environment. Thus the user could determine the cardinal direction they were navigating to and from in the environment.

- Aerial feature image

  Each image of a feature had an icon which if clicked, displayed an aerial image. This showed the location of all features in the virtual environment along with the ones that the user was currently viewing highlighted in red.

- Aerial location image

The aerial location image was triggered when the user clicked on a dedicated icon for it. This image gave the locations of each of the panoramic scenes within which the user would navigate. There was a difference between the location of the scenes and the location of the features. The aerial location image was an attempt to reduce confusion caused by the disparity between images showing the location of features and images of the users' own location.

- Movie fly-over / VRML model

  Both of these features were effective as devices for providing the user with an overview of Holyrood Park. To this extent they functioned like the aerial images. However for the movie clip, the effect was far more impressive if not quite as clear since the resolution of the image was not as high as aerial images. Similarly the VRML model allowed the user to 'fly' over the virtual environment providing an aerial view of the park. The main difference between this and the movie clip was that the user was in control of where they navigated.

- Audio commentary

  Audio commentary accompanied entry to every new location in the virtual environment. Part of this commentary described the current location of the user in the virtual environment. This supplemented information from the aerial images and further added to the users' spatial awareness.

Navigation features:

- Hot-spot navigation

  Hot spots are selected areas of the virtual environment that if clicked, transport the user to another location in the environment (a different panoramic scene). The software could be configured either to zoom in slowly to the hot spot before fading to the next location or to cut directly to the next location. The former was used since it conveyed a better sense of moving through the environment.

- Button navigation

  Navigation buttons looked like directional arrows and pointed LEFT, RIGHT and UP. The LEFT button took a user back to a previously visited location. The RIGHT button allowed the user to visit the next location while the UP button reoriented the user, taking them to the start of the field-course. The navigation buttons were a direct nonlinear means of navigation through the virtual environment.

- Aerial location image

  Aerial location images could also be used for nonlinear navigation. Each of the location markers in the image if clicked, would take the user to that particular location in the virtual environment. This avoided having to reach that location through linearly clicking each hot spot. It was designed for users familiar with the layout of the environment who wanted to consult specific features without having to navigate through the entire field-course to do so.

Several new features were also included to improve understanding of the geology content. This included a glossary and a selection of online questions.

- Glossary

  The glossary contained descriptions of most of the geology terms used in the field-course. The glossary was contained in the HELP area of the virtual field-course.

- Online questions

  Online questions were included to aid understanding of the geology material. This feature consisted of eighteen interactive multiple-choice questions. When the students clicked on an answer to the question, they were given an immediate response.

Holyrood Park virtual environment was supported by a comprehensive user help facility. This was prompted by formative evaluation that suggested the interface was so heavily endowed with functionality that users might become confused when learning how to interact with it. One way of overcoming this was to include a HELP facility to support the user. This consisted of:

- Tutorial - A tutorial introduced the user to the functionality and the structure of the virtual environment. It contained two simplified scenes from Holyrood Park. The user followed the instructions in the bottom of the web page. Some of these instructions showed how to navigate in the virtual environment and consult information on a geology feature. The user could attempt these functions in the virtual environment at the top of the web page.

- FAQ's (Frequently Asked Questions) - In effect this was a troubleshooter list to aid users with any minor technical problems.
- Movie / VRML model - These two features were intended to be supplementary to the core information in the environment.
- References - Several links to further information on the geology of Holyrood park.
- Additional images - These included geology maps of the park, three-dimensional images of the area, and larger aerial location and geology images of the park.

7.1.2 Method

7.1.2.1 Design

The objectives for evaluation were three-fold:

- assess the usability of the interface and functionality of the virtual environment
- measure the acquisition of geological and spatial knowledge
- examine the impact of the virtual environment on individual cognitive styles

The design of the evaluation comprised a mixture of empirical and qualitative techniques. This relied on a test re-test methodology. Table 7-1 illustrates the design of the study. There were three groups in the experiment, two experimental: virtual reality (VR) and multimedia (MM), and one control (CTRL). Since the version of the geology field-trip presented to the VR group has been described above, the multimedia and control groups will be described here. The MM version of the geology field-trip contained the same content and functionality as the VR version. However, it did not contain any interactive three-dimensional panoramas. Instead it used static wide-angle images of the park. The interface presented information in a vertically framed web page. The left-hand frame displayed a menu of contents. Each item in this menu was a feature name and a number. If the feature name was clicked, it opened

Stage	Stage 1			Stage 2		Stage 3
Group	Pre-test	SUPP	Test 1	REAL	Test 2	Test 3
VR	RMPFB	VRFT	Spatial	FT	Spatial	Spatial
MM	Geo-pretest	MMFT	& Geo	FT	& Geo	& Geo
CTRL		CTRLFT	Tests	FT	Tests	Tests

Key: FT=real fieldtrip; VRFT=virtual reality fieldtrip; MMFT= multimedia fieldtrip; CTRLFT=paper fieldtrip

Table 7-1: Design of the evaluation study

a web page in the right-hand frame that described a geological feature using static images and textual descriptions. Clicking the number beside the feature name triggered a wide-angle static image. This had the corresponding number of the feature superimposed on it at the appropriate location in the actual environment. Finally, the control group (CTRL) was presented with a paper version of the MM environment with all associated maps and questions included.

7.1.2.2 Procedure

As shown in Table 7-1, the experiment was divided into three stages. In stage 1 all subjects received pretests via the Internet. These consisted of a general test of the Holyrood Park area and a standard test of spatial ability (the Revised Minnesota Paper Form Board test - RMPFB). The general test required subjects to recall any geological names associated with Holyrood Park and examined prior knowledge of the geology of the park. The participants then completed the version of the supplementary field-trip allocated to them. All versions contained the same content information and aerial images showing the location of geological features in the park. Participants were instructed to attend to:

- the geological features themselves: how they looked and were formed, and
- the location of features in Holyrood Park and their relative location to each other

The students were advised to work their way through the material twice to gain a comprehensive idea of what it was about. All subjects were allowed to browse the supplementary field-trip for a maximum of one hour after which they attempted the evaluation tests. These tests measured three aspects of participants' knowledge:

- conceptual knowledge of the geology features
- spatial knowledge of the geological features and the virtual environment
- opinions and attitudes towards learning and usability experience

Stage 2 involved participation on the real field-course. On this field-trip members of the Geology department brought the subjects on a 2.5 hour excursion around the geological points of interest of Holyrood Park. The participants were divided equally but randomly among the three demonstrators. The route corresponded to the supplementary field-trip. Participants were free to ask any questions that occurred to them. Following the real excursion participants took the evaluation tests soon after (they were allowed two days). One week after the real field-trip, participants completed further evaluation tests to examine their long-term memory for knowledge that they had acquired during the experiment. This was the third stage of the experiment.

7.1.2.3 Modifications to design

Several improvements were made to the experimental design. These included:

- Use of field research

Teaching of geology was examined and evaluated directly in the field. This created several logistical challenges from a project-design perspective.

- Better comparisons (VR X MM X CTRL)

This evaluation incorporated better comparisons of learning such as between the multimedia and the virtual versions with the paper-based control group. The inclusion of the MM group allowed for examination of the panoramic scenes using the RS technology. Any improvements to learning in the VR version could be attributed to the use of these more interactive and immersive scenes. The control group allowed for comparison with textbook versions of teaching about geology.

- Post testing of subjects

Post-testing of subjects was incorporated into evaluation to examine the strength of the learning that occurred.

7.1.2.4 Methods used

- Revised Minnesota Paper Form Board test (RMPFB)

The Revised Minnesota Paper Form Board test (RMPFB) (Likert and Quasha, 1970) is a 64-item paper-and-pencil test of general spatial aptitude. Though the proper test is sixty-four items and twenty minutes long, this was considered excessive for an online version. Therefore a short form of the RMPFB was developed by using only the odd numbered items on the test. This left 32 items and consequently the time limit reduced to 10 minutes.

- Orientation tasks

Both the landmark and route tests were identical to those used in the Siccar Point evaluation. The only difference was that the content now referred to the features in the Holyrood Park environment.

Survey knowledge

Participants read a passage that described them standing at the location of a geological feature. They were then asked to show where they were in relation to another suggested feature (in egocentric terms: left, right, in front of or behind) or whether one geological feature was north, south, east, west, north-east, south-east, north-west or south-west of the other. The first question was a test of ego-centric spatial knowledge while the second was a test of geo-centric knowledge. Participants did this for three separate pairs of features at each testing stage.

Transformation knowledge

Transformation knowledge is the ability to switch from a route perspective to a survey perspective and vice-versa. Lanca (1998), hypothesised that contour map learning may require three-dimensional representations of the area depicted by a contour map. This is similar to what was being tested in the transformation tests. The virtual environment consisted of both route and survey perspectives of a location. Thus, the disruption experienced in processing this information was relevant to the design of navigation aids in virtual environments. Half of the transformation tests presented a bird's-eye view (survey perspective) of an area and required subjects to match it with one of four ground level (route perspective) images. The other half presented a ground level image and required subjects to match it with one of four survey views. These were known as transformation A and B tests respectively.

- Geological knowledge

The tests of geological knowledge focused on shallow-level knowledge (e.g. names of features) and deeper level knowledge (e.g. concepts and inferences). The geo-names task and the geo-knowledge task evaluated this difference between shallow and deep knowledge respectively.

Geo-names task

The geo-names task consisted of 20 feature names, ten of which referred to features encountered in the field-trip and ten not encountered before. The task was to tick those names that were recognised from the field-trip. Thus it was a test of recognition memory and as such did not require very deep understanding or elaborate memory to complete the task.

Geo-knowledge task

The geo-knowledge task evaluated the conceptual and inferential knowledge that participants had acquired during their exposure to the field-trips. This deeper knowledge referred to understanding of how features formed and their relation to the spatio-temporal geology of the area. The test was structured as six multiple-choice questions, each of which concentrated on one geological feature. The participant was required to answer the question by ticking one of five choices.

- Questionnaire data

The questionnaires supplemented the quantitative data by examining participants' attitudes to the experiment, from the usability of the interface to their feelings on how the experiment ran. Participants received three questionnaires: one after the supplementary field-trip, one after the real field-trip and one as part of the follow-up evaluation.

- Logging data

The logging data was derived from accesses to the files of the experiment by subjects. The data showed the number of times each page was accessed, the identity of the user, and the length of time the page was viewed.

7.1.2.5 Subject Profile

A total of 39 people began this study of which 19 were male and 20 female. However of these, 33 subjects completed all aspects of the experiment. The reason for the shortfall was mostly due to non-completion of a test or incorrect completion of a test. However where a subject has correctly completed a test then this is included in the calculation of statistics. Thus the effect is that subject numbers varied slightly between tests. Their average age was 24 years. Though not all subjects were students, of those who were, 24% studied subjects in the Arts while 76% studied science-based disciplines. All subjects were paid volunteers with no previous experience or knowledge of geology. However, 80% had visited Holyrood Park at least once. Of these 25% had only visited once, 54% between one and twenty times, and 21% had visited more than 20 times.

7.1.3 Results

A detailed presentation of results is given in Appendix C.

7.1.3.1 Geo-pretest

This was a free-recall test of features located in the Holyrood Park area. The number of geological features that subjects could remember was classified into three main categories. The first category *a/seat, crags* refers to the two best-known features in the park. Most residents in Edinburgh would know these. *Other* referred to any other features of a geological nature mentioned besides *a/seat* and the *crags*. Finally, the third category, *don't know* refers to people who could not think of any geological features location in the Holyrood Park area

Group	A/seat, crags	Other	Don't know	Total
MM	8	0	7	15
VR	7	2	5	14
CTRL	6	4	0	10
Total	21	6	12	39

Table 7-2: Index of information on the Geo-pretest

and by implication had no such geological knowledge of the area. Table 7-2 displays the indexed scores for the geo-pretest. This shows most of the subjects had little knowledge of the geological features of Holyrood Park before participating in the experiment.

7.1.3.2 Revised Minnesota Paper Form Board test (RMPFB)

A total of 39 students completed the shortened web version of the RMPFB. Data were compared across the three groups and a one-way unrelated ANOVA found no significant difference [$F(2,36)=2.84$, NS].

7.1.3.3 Orientation Tasks

- Landmark knowledge

Thirty-four subjects took this test. Performance improved across the three stages of testing. This was replicated in several spatial tests suggesting 'practice effects' among subjects. While the VR group marginally outperformed the others at stage 1 [a multiple 3x3 way ANOVA: $F(2,62)=63.02$, $p<0.001$], this disappeared with the superior performance of the CTRL group in stages 2 and 3. A multiple 3x3 way ANOVA found no significant difference for groups or the interaction [$F(2,31)=1.34$, NS].

- Route knowledge

Thirty-four subjects took this test. CTRL outperformed the other groups at stages 1 and 2 but this was superseded by MM for stage 3. The VR group by contrast performed poorly overall. A 3x3 way mixed ANOVA found no significant main [group: $F(2,31)=2.09$, NS; route: $F(2,62) =0.26$, NS]or interaction effects.

- Survey knowledge

Thirty-two subjects took this test. Results improved for all groups across the three stages of testing. Performance in each group varied at each stage with the MM group performing best in stage 1 followed by VR. The CTRL group outperformed the others in stages 2 and 3. This inconsistency of results was reflected in the non-significance of the 3x3 way ANOVA applied to the comparison of the groups [$F(2,29)=0.19$, NS]. However performance in the third stage of testing was superior [$F(2,58)=9.36$, $p<0.001$].

- Transformation task A

Thirty-four subjects took this test. Results for this test were mixed and inconsistent. CTRL outperformed other groups in two of the three stages (1 and 3) while VR performed best in stage 2. A 3x3 mixed ANOVA found no significant main or interaction effects [$F(2,31)=0.67$, NS].

- Transformation task B

Thirty-three subjects took this test. While MM and CTRL improved over the stages (VR the exception), the VR group consistently did either as well as (stage 2) or better than the other groups though these differences between groups across the three stages of testing did not reveal any differences [a 3x3 way ANOVA revealed: $F(2,30)=2.35$, NS]. A one-way unrelated ANOVA run on stage one data across the three groups found a significant difference in favour of the VR group [$F(2,36)= 1.42$, $p<0.05$]. Post-hoc Scheffé tests found the significant difference to lie between the VR and CTRL groups.

7.1.3.4 Knowledge Tasks

- Geo-names task

Thirty-five subjects took this test. For the first stage, performance improved from VR through MM to CTRL. However by the second stage of testing while all groups showed a downward trend, the VR group performed particularly poorly. A 2x3 way ANOVA found significant differences for groups [$F(1,32) = 13.28$, $p<0.01$] (with the difference between VR and MM on the second stage of testing), and the interaction [$F(2,32) = 4.70$, $p<0.05$].

- Geo-knowledge task

Thirty-four subjects took this test. As Figure 7-1 illustrates, results demonstrated superiority in performance for the VR group at every stage of testing and a 3x3 way ANOVA demonstrated this fact [F(2,31)=6.1, p<0.001]. This difference was most marked between the VR and MM groups and an independent measures t-test, for the three stages combined, found this was significant [t(23) = -3.45, p<0.01].

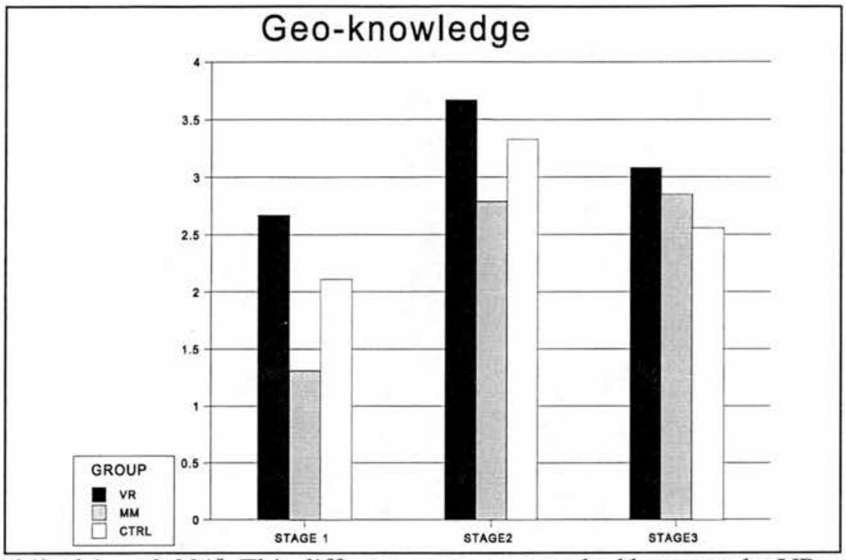

Figure 7-1: Mean scores across stages and groups for the geological knowledge test

Summary of results

The superiority of the VR group on the conceptual knowledge test was a noticeable feature of the results. At the supplementary field-trip stage, VR group did best on the landmark test (though this was not significant) and the transformation B test. These suggest that the performance of the VR group declined more rapidly in later stages of the experiment than for either of the other two groups. Thus any learning that did occur under the virtual environment is less likely to be remembered approximately a week later.

A multiple step-wise regression analysis found that performance on the landmark test, was a significant predictor of performance on the Geo-names test [T= 2.34, p<0.05]. Similarly performance on the route test was a significant predictor on the geo-knowledge test [T = 2.67, p<0.01].

7.1.3.5 Individual differences

Subjects were categorised as either high or low in spatial ability (hi- or lo-spatial respectively) based on performance on the RMPFB test. Analyses of individual spatial differences are given just for the first stage of testing (Figure 7-2). This is the stage in which the different versions of the field-trip would have most impact on the individual differences between subjects.

- Landmark 1 test:

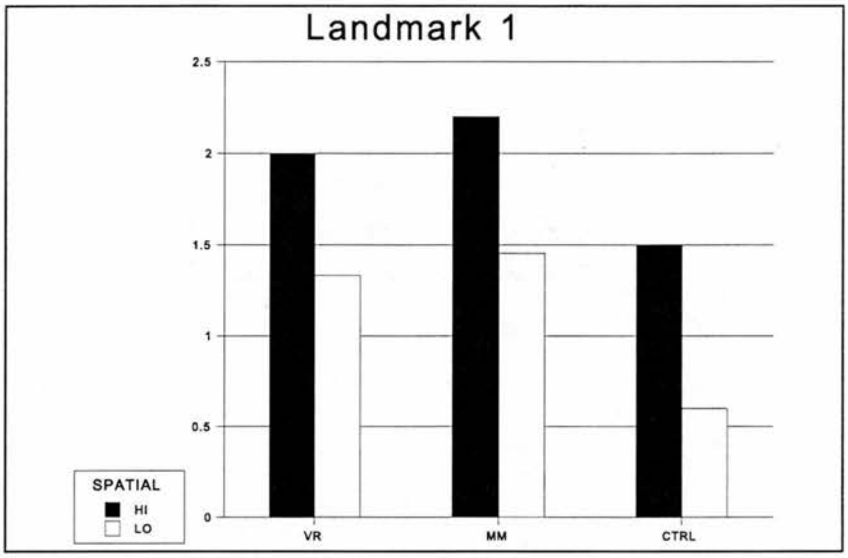

Figure 7-2: Mean scores across stages and groups for the landmark knowledge test

Most notable is the dominance of the hi-spatial subjects across all conditions. The smallest gap between the hi- and lo-spatial groups was for the VR group. This suggested that the technology had a less divisive effect and supports a greater variety of cognitive styles than the other versions of the field-course. A 2x3 way multiple ANOVA found no difference between groups [$F(2,31)=1.85$, NS], but did find an overall difference between high and low spatial subjects [$F(1,31)=4.9$, $p<0.05$].

- Route 1 test:

Note the smaller difference between lo- and hi-spatial in the VR condition (Figure 7-3). A 2x3 way multiple ANOVA found no difference between groups [$F(2,31)=2.51$, NS], or between high and low spatial subjects [$F(1,31)=3.7$, NS]. The difference between hi- and lo-spatial subjects in the MM version was approaching significance [$t(13)= -2.07$, $p<0.057$].

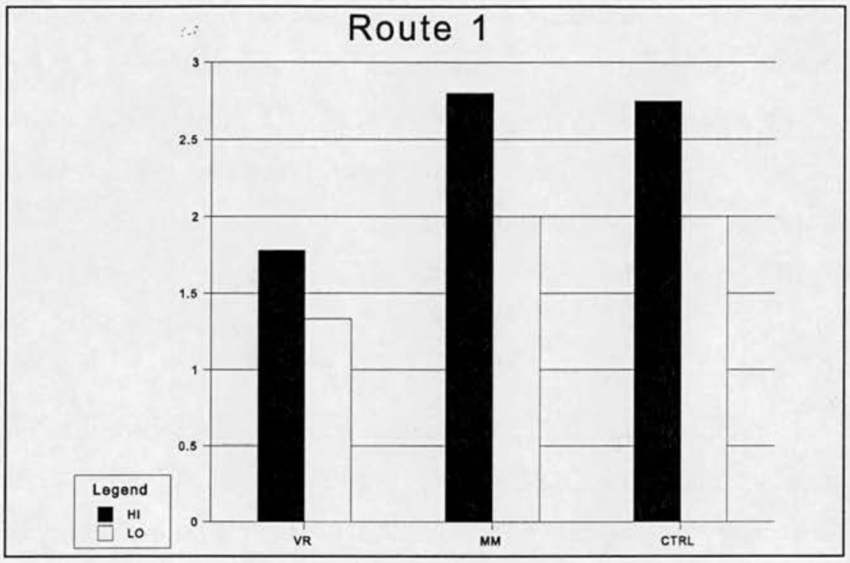

Figure 7-3: Mean scores across stages and groups for the route knowledge test

- Survey 1 test:

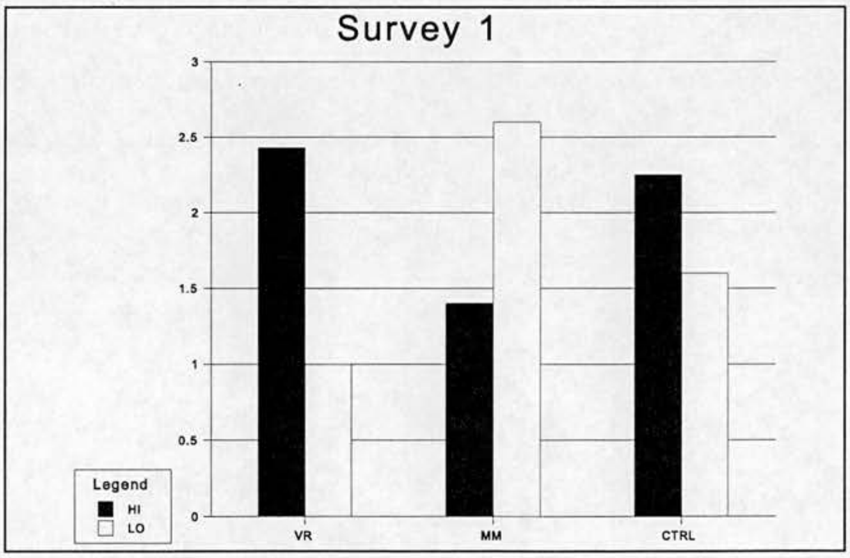

Figure 7-4: Mean scores across stages and groups for the survey knowledge test

Findings for the Survey test were mixed (Figure 7-4). The hi-spatial group predominated for the VR and CTRL versions. However within the MM group, the lo-spatial subjects did better and indeed outperformed all other groups. This was approaching significance [t(13)= -2.14, p<0.052]. Also, the performance difference between the lo- and hi-spatial groups was greatest for the VR version. The lo-spatial subjects of the VR group had the lowest overall score. A 2x3 way multiple ANOVA found no difference between groups [F(2,28)=0.12, NS], or between high and low spatial subjects [F(1,28)=0.36, NS]. On the third version of the survey test there was a significant difference between hi- and lo-spatial subjects for the CTRL version favouring the hi-spatial subjects [t(7)= 3.42, p<0.05].

- Geo-knowledge test

For both VR and MM, the lo-spatial subjects out-performed their hi-spatial counterparts (Figure 7-5). This was the opposite for the CTRL subjects. A 2x3 way multiple ANOVA reflected these differences between groups [F(2,31)=7.15, p<0.001], though did not identify a difference between high and low spatial subjects [F(1,31)=1.89, NS]. The VR version produced the largest difference between the hi- and lo-spatial subjects with the lo-spatial subjects outperforming all other subject groups and this was very significant [t(8)= -3.6, p<0.001]. These findings lend support for the notion that combining the spatialising features of the virtual environment with meta-cognitive tools such as the interactive feedback questions contributes to higher levels of learning than would otherwise be the case. This is especially so for the lo-spatial subjects who appear to benefit most from such features. This pattern of results was repeated on the follow-up test of geological conceptual knowledge (Figure 7-6) though no significant differences emerged.

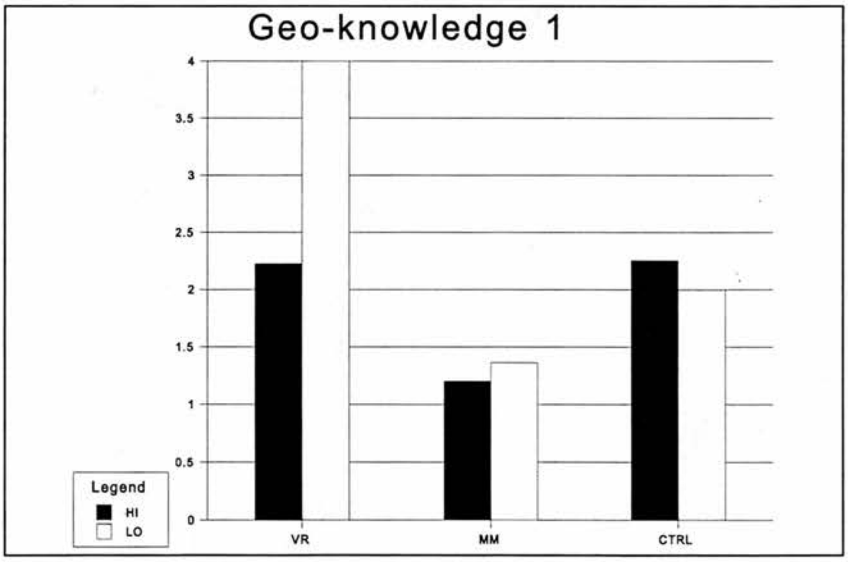

Figure 7-5: Mean scores across stages and groups for the geological knowledge test

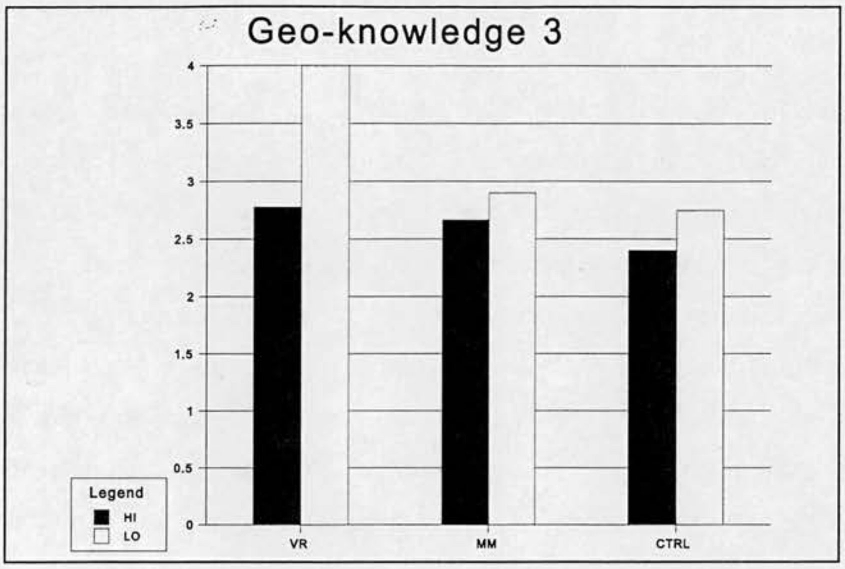

Figure 7-6: Mean scores across stages and groups for the geological knowledge test

7.1.3.6 Native and non-native English Speakers

The subject sample included ten non-native English speakers distributed across two conditions (VR and MM). It was possible that this may have been a confounding variable since most of them (7) were in the VR group. Native English speakers did perform consistently better across all tests except transformation B test. This difference was significant for stages 1 and 3 of the landmark test, stage 1 of the route test and stage 2 of the geo-names test.

Comparisons of the native English speakers across conditions showed that the CTRL group outperformed both VR and MM on the spatial tests. However, this superiority was inverted in favour of the VR group for the Geo-names and Geo-knowledge tests. The VR group did worse than both the other groups on five out of the nine spatial tests. This is in contrast to the non-native speakers for whom performance in the VR condition was consistently superior across the same spatial tests. However VR group performance among native English speakers was significant for the geo-knowledge task in the first [$t(15) = -3.22$, $p<0.01$] and second [$t(14) = -2.47$, $p <0.05$] stages. A significant difference was also found for the Geo-names test favouring MM group over the VR group [$t(14) = 3.88$, $p<0.01$].

7.1.3.7 Usability and qualitative results

- Questionnaire 1

This questionnaire was administered immediately after subjects completed the supplementary field trip. It was concerned with the usability of the tools particularly within the VR group.

VR subjects reported the highest levels of dissatisfaction (3.33 on a scale of 5). Reasons included the quality of static pictures and the amount of text, while the MM group was unhappy with the quality of location information. Subjects found the tutorial useful (3.83 out of 5). While most used the audio clips for presenting information, nine out of twelve subjects preferred the use of both text and audio than either alone. Most also found the movie clip beneficial for comprehending the material. Compass points and aerial images with geological features were both rated as most effective for providing location information, with compass points being most often used. The fly-through movie was rarely used possibly due to its obscure location in the interface. Hot spots were rated the most effective form of navigation followed by navigation buttons and aerial images with location markers. The questionnaire also found high use of aerial images across all groups with the VR group making most use of them. The VR group felt most immersed (2.67 out of 5). However the CTRL group rated their feelings of immersion quite close to this while MM felt least immersed. When asked about using the online geology questions 10 out of 12 subjects in the VR group found them helpful for learning about the geological features. The CTRL group found the orientation tasks most difficult (4.00) followed by MM (3.77) and VR (3.42). The VR group suggested the inclusion of more audio and animated images in future versions of the field-course.

- Questionnaire 2

The second questionnaire examined learning during the real field trip. The VR group found that their understanding of the real field trip improved through using the supplementary virtual field-trip. This was more pronounced than for either of the other two groups. Most subjects reported high levels of orientation to their surroundings when on the real field-trip with an average rating of 4.19 (out of 5). The VR group reported the least amount of orientation. Most subjects (79%) thought that the real field-trip was superior for learning the geological features of the park. A greater percentage (91%) chose the real field-trip over the supplementary field-trips for teaching about the location of features in the park. Additionally, 32 out of 33 subjects thought that the supplementary fieldtrip should supplement rather than replace the real thing.

- Questionnaire 3

This questionnaire focused on what the subjects thought of the entire experiment. All subjects expressed a high level of enjoyment with the mean rating for the VR group being slightly higher (4.58 out of 5) than other groups. Subjects were then asked to rate from 1 (easy) to 5 (difficult) each of the spatial tests for difficulty. All of the spatial tests were rated as difficult. The most difficult was the survey test while the easiest were the transformation tests. VR subjects more than the other two groups thought the tests were difficult except for the transformation test.

Despite their relatively poor performance on the spatial tests, the VR group reported considerably better representations for the general layout of Holyrood Park than the other two groups. This was possibly due to the high prevalence of aerial images for this group. However, no group was superior for their memory of the location of the geological features. The VR group retained some memory for the features at stages one and two, but this trailed off for the final stage of testing (one week after the real field-trip). This suggests that the VR tool did not create long-term memories of the location of the geological features.

7.1.4 Discussion

7.1.4.1 Key Findings

- Performance of VR group in landmark and the transformation B tasks

VR subjects outperformed the other groups on the landmark test though this was not significant. This shows that the VR version was most likely to support performance on at least one spatial test. One reason for this may have been the method of placing the labels of the features directly over the area in which they are found in the panoramic images. This gives the user a direct link between the feature name and its location. It is an example of how spatial and semantic information may be combined to enhance learning. The MM and CTRL versions used the number location method similar to Siccar Point. Otherwise performance by the VR group of the spatial tests was no better than the CTRL group. Possible reasons include the usability of the interface (see below).

Though the VR group did perform significantly better on the transformation B test, this result is problematic. The task was easier for the VR group because some images used for the test were taken directly from the virtual environment. Thus VR subjects may have recognised aspects of the images and thus had a better chance of matching the ground level view with the aerial view of the feature.

- VR performance on geo-knowledge task

In the introduction a meta-cognitive tool was described as forming part of the virtual version of the field-course. This tool consisted of interactive feedback questions. Feedback on each answer was included so these questions could be regarded as feedback-learning prompts that the student could refer to as they navigated through the field-course. In this sense they were designed to induce reflection on what had been learned in the student and hence were thus described as being meta-cognitive. The multimedia and control groups did not have such a facility. Use of such tools was discussed in chapter 2 for implementing a more eclectic approach to learning. The inclusion of the feedback questions may have enhanced performance on the test of geological conceptual knowledge. The effectiveness of meta-cognitive tools for enhancing this type of knowledge is examined more directly in later experiments.

- Correlation of the route and landmark tests with geo-knowledge task

Both the MM and CTRL field-trips provided a simple list of contents that, in the case of MM, was clickable. In the CTRL version subjects simply turned the pages of the hand-out to go to the next feature. Thus, the conceptual information was similarly presented in such a manner. This was also the case for the VR group where conceptual information for a feature would appear when they clicked it at a particular location. It may be the case therefore that the linear presentation of conceptual information makes that information more 'learnable' in that it classifies it in a more memorable way.

- Correlations of the landmark and route tests with geo-names task

The correlation with the landmark test is best explained by the fact that the features themselves were essentially landmarks. Aerial images of the park were indexed by the feature names in their appropriate locations and so an association developed between the feature name and its location. The feature names were also encountered linearly. Thus, the link between a feature name and its position in the order of features may have contributed to the correlation between the geo-names and route tests.

- Negative correlations between RMPFB and spatial tests

The full version of the RMPFB is regarded as quite a robust measure of general spatial ability.

However it is suspected that the delivery of the RMPFB over the web and the fact that this version was shortened may have compromised its validity.

- Performance of hi-spatial group on landmark and route tests and the smaller difference between the hi-and lo-spatial groups for VR

These trends contrasted with the Siccar Point evaluation. In the present experiment the hi-spatial group benefitted most from VR versions of the field-course and correspondingly did best on the spatial tests. However, the difference in the performance of the hi- and lo-spatial groups is smallest for the VR version of the field-trip. This suggests either that the hi-spatial group benefits less with VR or the lo-spatial subjects benefit more from the VR version.

- Hi-spatial dominance for VR and CTRL on survey test

On this test the discrepancy in performance between lo- and hi-spatial subjects was largest for the VR group benefitting hi-spatial subjects. The MM version appeared to benefit the lo-spatial subjects to a greater extent. One explanation is that the aerial image may have benefitted the MM and CTRL subjects more than the other groups due to the ease with which they could refer to it. By contrast the VR subjects reported some difficulty with down-loading the aerial images and some did not refer to them as often as other groups. Hi-spatial subjects in the VR group were better able to make use of the available spatial aids for attempting the survey test than were the lo-spatial subjects. Given that it was a difficult test this may have served to exacerbate underlying difficulties that the lo-spatial subjects were experiencing as evidenced by their performance on their other spatial tests. Thus the inclusion of the spatial aids across all versions of the field-trip served to benefit those subjects that were more spatial in their cognitive style. However the VR version was the only one that supports the lo-spatial subjects for two of the three spatial tests.

- Dominance of lo-spatial subjects on geo- knowledge tests and difference between lo- and hi-spatial subjects for the VR version

It is thought that hi-spatial subjects were more distracted by the visuo-spatial features of the field-course. Consequently they dedicated less attention to the completion of the meta-cognitive questions that probably contributed to the enhanced performance by the VR group on the geo-knowledge test. The lo-spatial subjects may not have focused on the spatial elements of the field-course preferring instead to concentrate on the textual features. This distraction by the spatial elements may have had more to do with the way hi-spatial subjects approach information. Hi-spatial subjects may approach the learning of their information in a more top-down, non-linear manner, preferring to 'jump around' the virtual environment rather than working through it linearly. This possibly contributed to poorer performance on the conceptual knowledge test since they may be less likely to connect the meta-cognitive questions to the text it related to. Added to this is also the possibility that the lo-spatial subjects may be more verbally proficient than their hi-spatial counterparts. It is notable that lo-spatial subjects in the other groups also outperformed their hi-spatial counterparts except the CTRL group in the first stage of testing. Thus lo-spatial subjects may have developed better non-spatial strategies for acquiring information than hi-spatial counterparts. This possibly contributed to their better performance on the geo-knowledge test.

7.1.4.2 Interpretation of qualitative results

VR subjects reported feeling oriented in the virtual environment and possessing good memories for the environment and its features. This contrasted with their poor performance on the spatial tests. If anything their poor performance on such tests negatively correlated with their reported levels of difficulty on such tests. These findings raise two important questions concerning the spatial tests:

1. Are such tasks a valid measure of spatial knowledge?

The validity of the spatial tasks (though not standardised) was determined by their use in previous studies (e.g. Satalich, 1995). In a controlled study she successfully used variations on the tests to examine spatial knowledge acquired from virtual environments. In the present experiment the testing environment was not so controlled. This was an inevitable part of it being a field-study in a naturalistic environment.

2. Did the subjects use strategies to answer questions that did not require spatial knowledge of the Holyrood Park area?

Subjects reported using a variety of strategies to answer each test. Some subjects even combined several strategies in a single test. In the landmark test MM subjects complained that if one forgot the feature names then one was unable to do the test. Thus, memory for the names of features was almost as important as the features themselves in this test. A second issue was that many people used a route-based strategy to match the features. Comments such as "I tried to remember where the feature was with respect to the route taken" indicate the order that features were encountered was used as a mnemonic for remembering their location.

Comments on the route test revealed use of two main strategies. Subjects either attempted to remember the route they had taken from the real and virtual trips (as expected), or they adopted a survey view of the entire park and attempted to answer the questions from that perspective. However the precise type of spatial information in this test (the linear ordering of the features) is also a mnemonic. The structure of the CTRL and MM field-trip contributed to good performance on this test. In the survey test, while some subjects used a map-like overview of the entire park to relate the features to each other, others used route-based strategies. Finally the transformation tests suggested a strong use of feature- matching. Instead of relying on spatial memory, most subjects matched the aerial and route images with their surface features. Thus the exercise became a perceptual rather than a spatial one.

It is clear from the above analysis that subjects used a variety of strategies (some spatial, some not) to solve the spatial tests. Thus it is assumed that individuals will use those strategies they think are most efficient for time and effort.

7.1.4.3 Comments on the Evaluation

- Heterogeneity of the subject population

Approximately 40% of the subject sample were non-native English speakers. Despite trends suggesting superior performance of native English speakers only a few of the differences were significant. These results validate the idea of performance being dependent on the condition an individual was assigned to rather than due to understanding of the English language. However performance on the landmark and geo-names tasks should be interpreted with caution since on these tests the differences between the native and non-native speakers were significant.

- Usability issues

Responses from the questionnaire data highlighted several usability issues. Subjects reported that the orientation features of the supplementary field-trip were not a priority. Instead familiarisation with the technology, and then the learning of the geology was most important. Subjects felt it important to learn about the geology since it was after all a *geology* field-trip as opposed to one about spatial orientation. Additionally, many spatial orientation features in the VR version were left implicit. Thus some subjects were surprised and eventually frustrated when required to answer the spatial tests since they felt that they were irrelevant. A related issue was that subjects were only given a single exposure to the virtual field-trip (as for other groups). This mostly affected the VR and MM groups since they had to familiarise themselves with the interface before learning anything. The floor effects in many tests, suggesting that subjects found them quite difficult to answer, support this.

Finally, other usability problems included screen resolution and lack of detail in the images. Controlling the memory and bandwidth demands of the virtual field-trip was a constant challenge. This was compounded by use of medium specification machines with problematic network configurations. The size of the monitors (14 inches) made scrolling through the virtual environment necessary and resulted in certain icons scrolling off the screen and being often forgotten.

Conclusions

This evaluation showed that image-based desktop VR is equivalent to web- and paper-based media for the acquisition of spatial knowledge in a geology field-trip. The virtual field-trip was most effective for acquiring conceptual geological information. Furthermore the simultaneous presentation of relevant spatial information with geological content may have resulted in improved learning of that material.

Invariably this study raised more questions than answers. In particular the role of the meta-cognitive feedback questions for enhancing conceptual geological knowledge required further investigation. Results from the research on individual differences were less clearly defined due to the possible invalidity of the RMPFB test. However, some consistent trends did emerge such as the remedial effect of the VR version for lo-spatial subjects.

Finally, despite the improvements to the interface, many usability problems remained. From the usability data it was evident that these were due to the structure of information in the interface and attempts to place too much information in front of the user at once. What was required was a *lighter* interface with intuitive easy-to-use controls preceded by a basic grounding in how to use the technology.

7.2 Evaluating embedded feedback questions

This section describes experiments carried out with the Psychology department to discover whether the inclusion of interactive or meta-cognitive feedback questions in a textual passage enhanced comprehension for it. Experiment 2 suggested that VR subjects did significantly better on a conceptual knowledge task than other groups because only they had received such questions in their presentation. There is evidence that including summaries and questions at the end of a piece of text can enhance comprehension of that text (e.g. Mayer, 1984). To test this hypothesis, two experiments were designed. Experiment 3 contrasted the effectiveness of interactive feedback questions for conceptual learning with no such questions. If such questions did enhance comprehension, then it begged the question whether any superiority in performance would remain for the VR group after the removal of such questions? Experiment 4 was a partial replication of the first Holyrood Park evaluation designed to resolve this issue. Thus the two experiments were complimentary and it was expected that they would support each other in their conclusions. In addition, the replication of the Holyrood Park evaluation incorporated features designed to improve the general validity of the research.

7.2.1 Experiment 3: Effects of feedback questions on comprehension

This experiment investigated the effects of embedded feedback questions on comprehension of a textual passage.

7.2.1.1 Method

This was an independent measures experiment with one independent variable (GROUP) and two dependent measures: a surface-level recognition test (NAMES test) and a conceptual knowledge test (QUIZ). Thirty-two subjects participated of whom 15 were male and 17 female, however as with previous experiments subject numbers vary from test to test due to improper completion of a test and subsequent withdrawal of a subjects results. Subjects were student volunteers from Edinburgh University Psychology department and were not paid for participation. All subjects were native English speakers.

Subjects were presented with a computer-based multimedia presentation of a geology field-trip. The presentation is approximately fifteen hundred words in length, spread across twenty-two web pages and interspersed with one or two images on each page. The text describes in moderate detail, the kinds of geological features one can expect to find at Holyrood Park. Difficult terms are described in an online glossary.

Subjects were randomly assigned to three groups. Group one was assigned to the MIDDLE condition. This meant that they were presented with the text on Holyrood Park but this version included a selection of 14 feedback questions embedded at relevant points along the presentation. These feedback questions were similar to those used in the VR version of the first Holyrood Park study. The questions were multiple-choice. Each question had up to five potential answers. When the subject clicked on an answer, it revealed whether it was the correct answer or not. The subject was also provided with information that elaborated the answer. They were then free to click on each of the alternate answers until they came upon the correct one. In this way the subject was always learning something of the geology of the park. Group two was assigned to the END condition under which they received the same feedback questions at the end of the geology presentation. Finally, the control group did not receive any of the questions. An example of a feedback question is shown in Figure 7-7.

Having read the geology passage, all groups were required to engage in a distracter task that involved reading the preface of an introductory statistics textbook. This was inserted so that the group receiving the feedback questions at the end would not benefit by having a shorter time-span between receiving feedback questions and answering tasks. Following the distracter task all subjects were presented with the NAMES test. This test examines surface level knowledge through a recognition test of the geological feature names. This was followed by the test of conceptual geological knowledge that consisted of eighteen multiple-choice questions. Following completion of the tests all subjects were given a short online questionnaire to fill out. This asked

Question:
At the Hawse there are drill holes where samples have been collected for palaeomagnetic analysis. What do the results demonstrate?

1. The dolerite was intruded at a temperature above 578°C
2. At the time of intrusion Scotland lay a little north of the equator
3. The dolerite was intruded during a period of reversed polarity
4. The dolerite is not sufficiently magnetic to obtain meaningful results
5. The dolerite contains magnetite

[Subject clicks on answer no.1]
Incorrect!

Answer:
The dolerite was intruded at a temperature above 578°C

Comment:
This is the Curie temperature of magnetite and the dolerite certainly was intruded at a higher temperature. However, palaeomagnetic measurements are obtained for more significant purposes.

Figure 7-7: Example of embedded feedback question from Experiment 3.

for personal details such as age, sex and familiarity with Holyrood Park.

7.2.1.2 Results

Table 7-3 shows means and standard deviations for the groups on the NAMES test. A one-way ANOVA found no significant difference among the three groups [$F(2,28) = 0.766$, NS].

Group	Mean	SD	Cases
Middle	8.54	1.43	11
End	7.88	1.61	9
Ctrl	8.54	0.93	11

Table 7-3: Means and standard deviations for the NAMES test in Experiment 3.

The results of the conceptual knowledge test are given in Table 7-4. The MIDDLE group answered more questions correctly than the other two groups thus suggesting that embedding the feedback questions in the text enhances comprehension. The END group and finally the control group followed this. A one-way ANOVA found these differences were highly significant [$F(2,27) = 14.72$, $p<0.0001$]. Post-hoc comparisons, in the form of independent measures t-tests, found significant differences between MIDDLE and END [$t(17) = 2.55$, $p<0.05$], and between END and CONTROL [$t(18) = 2.62$, $p<0.05$].

Group	Mean	SD	Cases
Middle	12.10	2.55	10
End	9.22	2.33	9
Ctrl	6.81	1.77	11

Table 7-4: Means and standard deviations for the QUIZ test in Experiment 3.

7.2.1.3 Discussion

The MIDDLE group outperformed the other conditions on the conceptual knowledge test. While it was expected that including feedback questions would increase comprehension over control conditions, it was not certain whether this condition would outperform the END group. Lack of significant differences in the NAMES test revealed ceiling effects. This test should be made more difficult to better discriminate between groups.

The conclusions of this experiment support the hypothesis that the including feedback questions in the original experiment contributed to superior performance on a conceptual knowledge task. However to confirm this possibility it is also necessary to replicate the original experiment as much as possible but without the original feedback questions. This is to discover whether the performance of subjects in the modified VR condition would also support the hypothesis.

7.2.2 Experiment 4: Holyrood Park replication

This was a partial replication of the original Holyrood Park study. It was undertaken to exclude the effects of including embedded feedback questions, which as shown, do contribute to enhanced comprehension of a passage of text. It replicates the first stage of the experiment by which subjects took the supplementary version of the field-trip. Modifications included removal of feedback questions and prevention of aerial images from appearing at the start of every new location. These images were transferred to the lower frame of the web page where they could be viewed by choice and would load more quickly. The navigation controls were also modified so those subjects could only move forward via the system of hot spots. This allowed for somewhat more intuitive movement through the virtual environment.

7.2.2.1 Method

The experiment was a between-measures design with three levels of one independent variable (GROUPS (VR x MM x CTRL)) across two dependent variables: SPATIAL and GEOLOGICAL knowledge. Twenty-eight subjects participated (14 males and 14 females), whose mean age was 20 years. Again, subjects were student volunteers from Edinburgh University Psychology department and were not paid for participation. All subjects were native English speakers.

Subjects were randomly assigned to three conditions. Condition one was a virtual environment presentation of a geology field trip (VR). The second group of subjects (MM) was presented with a multimedia version of the field-course. This version is identical to that used throughout the three conditions in the previous experiment (experiment 3) Finally, the control (CTRL) group received a paper version of the MM presentation. Nine subjects each were assigned to the VR and CTRL groups and ten to the MM group.

All subjects received the paper-folding subscale of the Kit of Factor-Referenced Cognitive Tests

(Ekstrom et al., 1976). This was a test of general spatial ability chosen for its simplicity and conciseness. The test is also short, taking no more than six minutes to complete. More importantly the test boasts good predictive validity (Anastasi, 1988). Once the spatial test was completed, all subjects began the experiment by logging-in to the computer. While the VR and MM groups went on to their respective on-line presentations, the CTRL group was instructed to read their paper version of the field-course. Once the different versions were completed, all groups were given a series of evaluation tests and a questionnaire to complete. The tests examined two types of information. The NAMES and QUIZ tests examined any geological knowledge that may have been acquired from the presentations. These tests were identical to those described in the previous experiment. Three additional tests examined spatial knowledge. These were the LANDMARK, ROUTE and SURVEY tests. These tests were identical to those presented to subjects in the first Holyrood Park evaluation. Finally, subjects were given a questionnaire on their previous experience of Holyrood Park and any thoughts on the various parts of the experiment.

7.2.2.2 Results

A detailed presentation of results is given in Appendix D. No significant difference emerged between the groups on the paper-folding test. Thus any further differences that emerged on the spatial tests could be attributed to them and not to differences in individual spatial ability. Figure 7-8 shows the mean results for all three groups across all tests in the experiment.

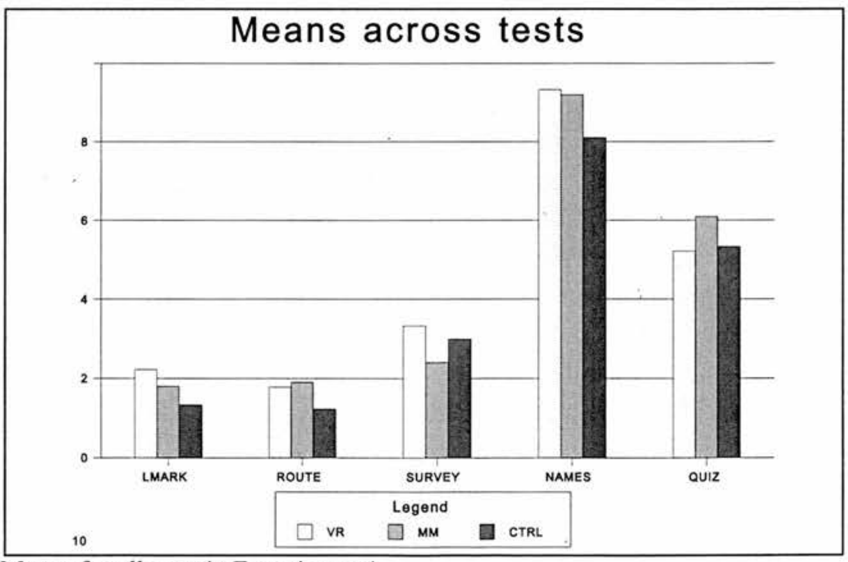

Figure 7-8: Means for all tests in Experiment 4.

No significant differences between groups were recorded from the series of one-way ANOVA's carried out. Trends showed a slight advantage for the VR group on the LANDMARK and SURVEY tests though this was reversed in favour of the MM group on the ROUTE test. While a very slight advantage was recorded for VR on the NAMES test, this disappeared in favour of the MM group on the QUIZ. However, the VR group consistently did better than the control group (CTRL) across all of the spatial and knowledge based tests (except the QUIZ test). This is a much more positive and consistent result than that found for the original Holyrood Park experiment

From performance on the paper-folding test, a median split of the highest and lowest scorers were identified and matched to their performance on the spatial and non-spatial tests. This was carried out to identify any relationship that might exist between spatial ability and performance on the other tests in the experiment. There was a definite trend in favour of hi-spatial subjects (Figure 7-9) though this was not significant. Across all the tests (both spatial and knowledge based), hi-spatial subjects outperformed their lo-spatial counterparts. However, of most interest are the exceptions to this trend. On the LANDMARK test for example, the lo-spatial VR group did better than their hi-spatial counterparts. Similarly lo-spatial subjects outperformed hi-spatial's on the ROUTE test for the MM group and on the SURVEY test for the CTRL group. Hi-spatial subjects outperformed their lo-spatial counterparts for all groups on both the NAMES and QUIZ tests of geological knowledge.

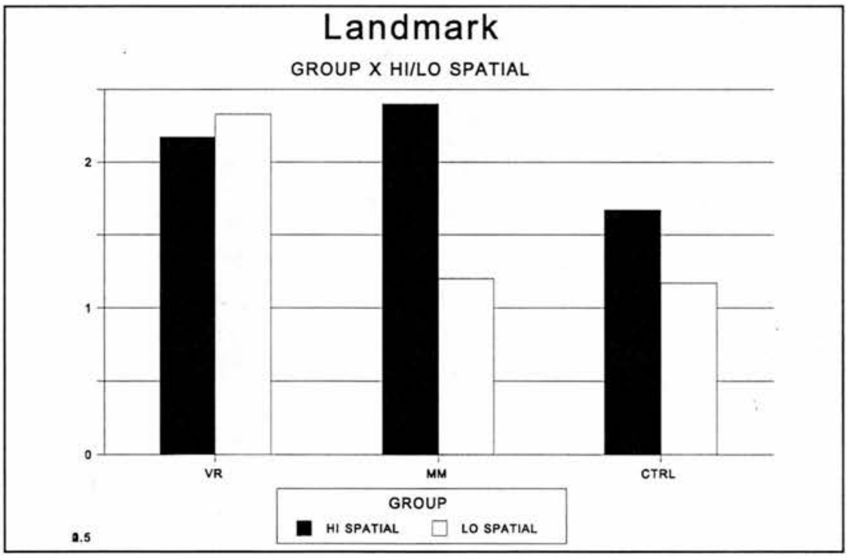

Figure 7-9: Mean scores on landmark test for GROUP X HI/LO SPATIAL.

The data was then collapsed into SPATIAL and NON-SPATIAL grouping (normalised data from the spatial and non-spatial tests). Subjects' performance on the various tests was compared according to whether they were classified as hi- or lo-spatial. Figure 7-10 shows that the VR version reduced the discrepancy between lo- and hi-spatial subjects on spatial tests. Though not significant, this is evidence of the remedial nature of the virtual environments for lo-spatial users and supports previous findings from the Siccar Point evaluation.

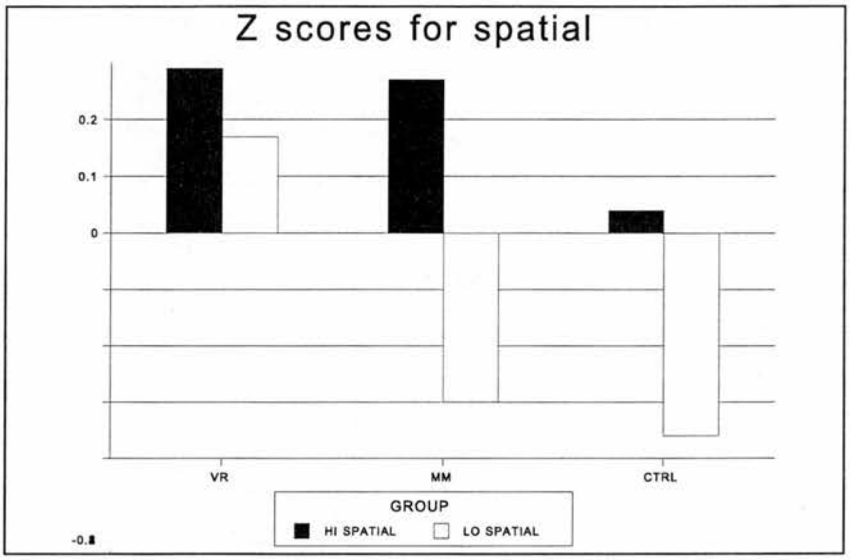

Figure 7-10: Z-scores among SPATIAL tests for GROUP X HI/LO SPATIAL.

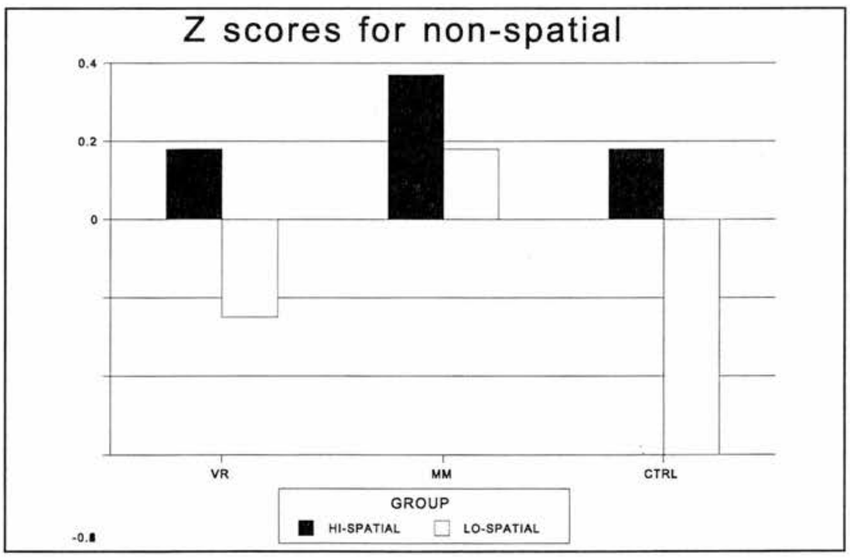

Figure 7-11: Z-scores among NONSPATIAL tests for GROUP X HI/LO SPATIAL

From Figure 7-11 one can also see the benefits of the technology with the lo-spatial subjects in the VR condition performing better than the CTRL subjects for non-spatial tests.

7.2.2.3 Discussion

The results of this experiment were weakly in favour of the VR group. Moreover, some interesting findings regarding individual differences did emerge. In the initial comparisons the VR group did modestly across the spatial tests except for the route knowledge test. This result was also found in the original Holyrood Park experiment. MM dominance of the ROUTE task was most likely due to the linear structure of the information. To view material a user typically clicked on the appropriate heading from the contents section and viewed it in the right-hand side. This pattern of working linearly from the contents section was observed in the data-logs. It illustrated how users simply followed the linear structure of the contents as they progressed through the material. Thus, the structure of the information in the MM version of the experiment was enough to influence subjects' memories for the information. The VR condition, though it too followed a linear route did not make the layout of this information so explicit. For CTRL, the contents page was the first page of the brochure. Once this was turned over, subjects were immediately presented with the content information. It is suspected that subjects most likely would not have returned to the contents page for each new feature that they encountered. This is similar to how most people read a magazine or book. Thus, the linear structure of the information is not made explicit to the CTRL subjects. Thus it was the structure of the contents area in the MM version that influenced users' memories for the information. It would be useful for future versions to completely eliminate the contents area from the MM version.

Results were mixed among the knowledge-based tests. No significant difference was found between groups on the conceptual knowledge test. This supports the hypothesis that embedded feedback questions do contribute significantly to learning and their removal therefore deprived the VR group of the advantage they experienced in experiment 2. For the NAMES test, the high scoring by MM and VR groups makes it difficult to interpret these results. It appears that the MM and VR groups are acquiring surface level information very well and if anything they are facing ceiling effects on this test. Thus, perhaps a more difficult version of the test needs to be designed to overcome this problem to better differentiate between the groups.

Individual cognitive differences also affected the results of this study. There was a consistent though non-significant relationship between high spatial ability and enhanced performance on all spatial and knowledge based tasks. Bucking this trend, lo-spatial subjects in the VR condition performed better on the landmark test than their hi-spatial counterparts. This suggested that VR had a subtle remedial effect on learning. Subjects of lesser ability benefitted to a greater extent from using a virtual environment to learn the information than from a multimedia or paper based version. This has important implications for the educational use of virtual environments if it persists. This finding is further supported by an analysis of the normalised data for the spatial and non-spatial tests combined and contrasted over hi- and lo-spatial groups. Here VR had the smallest gap in performance on the spatial tests between the hi- and lo-spatial subjects. Similarly on the non-spatial tests the lo-spatial subjects of the VR group outperformed the lo-spatial subjects from the CTRL group. Thus it would appear that the VR version of the field-trip supported the learning of subjects that are less spatial in their styles of thinking. Furthermore this effect was prevalent even on non-spatial evaluation tests.

7.2.3 General discussion

The impressive effects found for the inclusion of meta-cognitive questions in text shows how the structure of information and the way learning is directed through it can influence the acquisition of information. The meta-cognitive questions represent one aspect of an eclectic pedagogic framework that forms an integral part of the learning environments evaluated in this thesis. Other eclectic features of the environments included:

- comparisons of linear and free-form navigation through an environment
- interactive elements
- providing control of the content and pace of the learning to the learner
- provision of multiple perspectives
- provision of extensive user support facilities

These features could be improved upon with the following elements:

- inclusion of objectives for what has to be learned
- inclusion of content information relating to each panoramic scene
- make answers to meta-cognitive questions more comprehensive

A major issue has been an overestimation of the capability of users to understand and use the interface. Relatively poor performance in the QUIZ test may have been related to usability issues in the VR version of the field-course. The complexity of the interface meant that many VR subjects spent most of their time familiarising themselves with the controls instead of any worthwhile learning. This highlights the deficiencies in usability that plagued the virtual environment despite the improvements described above. The virtual environment may be made more usable in two ways: simplifying the interface and reducing downloading times.

It was generally accepted that the interface used in both Holyrood Park evaluations was cluttered, obscure and unintuitive. Additionally the tutorial was regarded as unhelpful and uninformative. Some instructions given in the tutorial section were obscure or so detailed that they were soon forgotten. These issues could be approached in two ways. First the interface could be simplified to reduce on-screen complexity so that the subject can concentrate on what is to be learned. Secondly the tutorial needs to be redesigned to be more relevant to the virtual environments of Holyrood Park. In the first instance the icons should always be available to the user so that they do not have to go searching for an explanation of them in a little-used HELP section. All information to do with the virtual field-course should be on the surface level where it is readily accessible to the user. The embedded HELP section should be removed and replaced by a demonstrator to supervise use of the technology and answer questions from subjects. Future versions should include a single demonstration tutorial in the use of the technology.

The poor network over which the experiment was conducted contributed to technical difficulties such as the slow downloading of images and panoramic scenes in the VR condition. For future evaluations, some of the largest files should be reduced or removed altogether to speed up transmission times. Here, the audio files describing each of the geological features are the biggest. Similarly, the enhancement images that bring higher quality detail to some panoramas could also be removed.

7.3 Experiment 5: the spatialisation of information

Chapter 3 describes a significant body of literature supporting the simultaneous presentation of spatial and non-spatial information and its effects on enhancing memory for both. From the research conducted so far, results showed a relationship between performance on some spatial tests and corresponding performance on the knowledge-based tests. This relationship was evident in both experiments 2 and 4. In experiment 2, correlation was noted between performance on the conceptual knowledge and feature-naming tasks with performance on the landmark and route tests. Similarly in experiment 4, correlation was noted for performance between the survey and the feature-naming task. This implies some form of connection between the spatial and knowledge-based tests. To explore this further, an experiment was carried out in collaboration with the Psychology department on the pedagogical benefits of combining spatial and non-spatial information in a single presentation.

7.3.1 Method

Using a between subjects design, 48 subjects (14 male and 34 female) were presented with one of four conditions for learning about the spatial and semantic information relating to a small town. Each condition varied by the way that this information was both presented and tested. In conditions one and two, subjects were presented with spatial and semantic information about the town either separately or combined. In the separate condition, subjects were presented with a page of building names. Under the names were three points relating to each building that made it distinctive and memorable. For example, for the building labelled the 'library', the three features were:

- blue interior
- has a disabled parking space out front
- has a large electric fan

Twenty such building names and their associated features were presented on a single page. Each name had a specific number attached to identify it. On a separate page an outline map of the town was shown with solid black circles symbolising the location of buildings. Radiating out from the map and attached to each circle was a line, at the end of that was a number corresponding to a number on the building page. Thus subjects could associate the names of buildings with their location on the map though the two types of information were presented separately. In the combined presentation condition, these two types of information were presented on a single map. Here each solid circle had a line radiating from it and at the end of the line was the name of the building and the associated feature descriptions.

Subjects studied the learning materials of the town for five minutes before taking a distracter task. They were then required to write down as many of the building names and descriptions as they could remember for the verbal test. Furthermore they completed a blank outline map of the town (buildings removed) with the location of as many of the buildings as possible (they were not required to name these buildings).

The second two conditions were similar except that during testing on the verbal test the subjects were spatially primed with a copy of the map with no text or numbers. Similarly subjects on the spatial test were verbally primed. This also involved a map without any building locations marked on it but with the names of the buildings included around its margins. Together the four conditions may be summarised as in Table 7-5:

Condition	Description	Label
1	Numbered map with separate textual information tested with non-primed tests.	Separate / basic
2	Combined map and information presented with non-primed tests.	Combined / basic
3	Numbered map and separate information tested with primed tests.	Separate / primed
4	Combined map and information tested with primed tests.	Combined / primed

Table 7-5: Description of conditions in experiment 5.

7.3.2 Results

Performance on the tests was indicated by the number of building names and descriptions the subjects could recall for the verbal test and their accuracy in correctly placing the location of buildings on the map in the spatial test. For the verbal test, one point was given for each correctly named building and one point for every descriptive feature. For the spatial test a template of the complete map was used. If any of the drawn dots overlapped the actual dots by at least half they were counted as one point. The results of the various tests applied across the conditions are displayed in Table 7-6.

Condition	Verbal		Spatial	
	Mean	SD	Mean	SD
Separate / basic	170.00	72.99	3.67	2.67
Combined / basic	222.50	41.97	4.67	2.19
Separate / primed	225.71	58.57	5.00	2.72
Combined / primed	225.00	74.87	4.00	1.94

Table 7-6: Means of verbal and spatial scores in each of the four conditions.

To allow for ease of comparison, this data was converted to percentages and the results are given below in Table 7-7.

Condition	Mean Verbal Percentage Correct	Mean Spatial Percentage Correct
Separate/Basic	21.25	18.34
Combined/Basic	27.81	23.33
Separate/Primed	28.21	25.00
Combined/Primed	28.13	20.00

Table 7-7: Means of percentage correct across each of the four conditions.

What immediately emerges from these results is the large difference in performance on the verbal and spatial tests between separate and combined presentations of the town information. Subjects presented with a map containing the locations, names and feature descriptors of buildings outperformed those that received the same information but on two separate pages. This difference was significant for the verbal task [$t(22)=-2.25$, $p<0.05$]. Similarly there was a significant difference between performance for the primed and the non-primed conditions when the information was presented separately. This was the case once again on the verbal task [$t(22)=-2.16$, $p<0.05$]. The lack of any difference between the separate-primed and the combined-basic conditions shows that priming worked in a similar fashion to the combined-basic condition to trigger a conjointly retained memory for the verbal material.

7.3.3 Discussion

The results of this experiment contributed to the research in the thesis. They clearly showed that the combination of spatial and conceptual information leads to improved memory for that information. The question further research needed to address was whether this enhancement could be generalised to learning within the spatialised display of a virtual environment such as Holyrood Park. Furthermore, the results only support memory for relatively low-level semantic information such as the names of buildings in the town. The additional question was whether such enhancement could be extended to conceptual geological information.

Additionally, the research only explained the enhancement for learning in terms of the conjoint retention hypothesis. However, priming research suggests that enhancements to learning from the spatialisation of information could also be due to the existence of spatial-propositional codes in spatial memory. This begged the question whether the existence of spatialised propositions could benefit acquisition of geological information in future evaluations of the Holyrood park virtual field-course.

A concerted effort to spatialise information is recommended for future evaluations. First, maps and aerial photographs could be included at every point where semantic information is presented to the student. However the selection and use of aerial images would have to be at the discretion of the subject. This is because compulsory presentation of the images was previously found to irritate subjects. Furthermore, the textual information describing the features themselves should be peppered with references to where that feature would be found in the park. This was used to good effect in the Kulhavy experiments.

Spatial information is more implicit in a virtual environment than was the case for experiments testing the CRH. The feature labels are placed over their locations in the real world; the compass features are placed on the horizon of the panoramas and the navigation aids are embedded in the navigation metaphor of moving from place to place. The key question is whether a virtual environment further enhances the facilitatory effects of conjointly presented spatial and semantic information.

7.4 Chapter summary

Four experiments are described in this chapter, each further refining the framework for learning with desktop virtual environments presented in chapter five. Moderate gains on tests of spatial knowledge are accompanied by impressive findings for conceptual knowledge. This is later attributed to the inclusion of interactive questions. Without these questions the remaining eclectic features are not as effective for enhancing learning. More effort is thus required to incorporate additional eclectic pedagogic elements in the learning environments. Additionally the effectiveness of spatialising information is demonstrated for paper-based learning materials. This is an important experiment since it demonstrates the effectiveness of the method by which spatialisation may occur and thus becomes a pilot for aspects of experiment six. Individual differences also emerge as an important element of the research with the finding that less spatial individuals are better supported by the VR technology suggesting possible remedial effects for virtual environments with this group. This is precisely the type of positive application that is required to encourage educationalists to adopt virtual environments as a viable learning tool. However this contrasts with continuing problems associated with the usability issue particularly among the VR conditions.

Overall, this chapter provides the first opportunity of the thesis to actually evaluate elements of each of the themes. While the limited results are positive, certain factors such as individual differences and usability begin to interact significantly with the research. A final evaluation is required to evaluate the various elements of the framework for learning with desktop VR as an integrated pedagogic structure; to see if what works can work together.

8.

Experiment 6: The Third Holyrood Park Evaluation

This chapter documents the final evaluation carried out on the Holyrood Park field-course. Results so far suggested modest but consistent support for the themes outlined in chapter five. Together they may contribute to a more informative description of the learning process in virtual environments. The previous chapter suggested further research was necessary to examine the interactions between the themes in the context of improvements to the usability of the technology. The research in this chapter was designed with this objective in mind.

8.1 Introduction

8.1.1 Objectives for evaluation

The main objective was to further evaluate the themes described in previous chapters using a more refined experimental methodology and improved usability.

- Affordances by virtual environments of spatial information

This theme is examined through the inclusion of virtual environment navigation aids in the virtual and multimedia environments. If the spatial characteristics of a VE favour inclusion and use of spatial aids then one should expect stronger performance on tests of spatial knowledge using VR over multimedia. Additionally, one would expect improved performance on those conditions that include the spatial features as opposed to those that do not.

- Spatialisation of information

This theme refers to the facilitatory effects of integrating spatial and semantic information in a single presentation. Where both types of information are presented conjointly, then one would expect better performance by subjects exposed to this presentation across both spatial and knowledge-based tests. This should be evident for both the virtual environment and multimedia groups but should be somewhat stronger for the VR group given the affordance for spatial information outlined above.

- Eclectic pedagogic approach

The eclectic approach to learning emphasises the importance of meta-cognitive information, extrapolation from the information and the inclusion of goal-directed but exploratory learning in a flexible environment. The specific inclusion of these pedagogical features should benefit both multimedia and virtual environment groups over control. However, they should particularly favour the virtual environment group given the added degrees of freedom enabled by such environments that should benefit the inclusion of the pedagogic features.

- Role of individual differences

These predictions are also affected by the importance of individual differences among subjects. Specifically differences in spatial ability and learning style (either serial or holist) are examined by two pretests administered at the beginning of the experiment. It is predicted that low-spatial subjects should find that learning in a virtual environment with spatial features is more beneficial than for subjects already competent in spatial ability. Furthermore holist subjects should find the inclusion of embedded feedback questions to be more supportive for their learning than those classified as serialist.

- Usability issues

The other main topic of interest in this evaluation is the qualitative data on the design of the tutorial and the interface. Significant changes were made to the structure and design of the tutorial and interface of the virtual environment. If shown to be successful in teaching the subjects about the environment then it could be adopted as a template for similar projects elsewhere.

8.1.2 Changes made to virtual field-trip

This version of the virtual field-course was the outcome of several modifications to the design of the experiment from both a theoretical and structural perspective. Many of these changes are based on recommendations made in the last chapter.

8.1.2.1 Changes to the experimental design

- Exposure to the environment

Exposure to the content was not properly regulated in previous experiments. This may have differentially affected performance across conditions. As a result all subjects were instructed to go through the virtual environment three times: once to familiarise themselves with all the facets of the environment; once to go through the environment learning the material in detail and once to go through quickly to refresh their memories on all the different features.

- Time allowance

Similarly the length of exposure was not regulated previously. All groups were limited to spending one hour in the virtual environment. This ensured that all subjects were given adequate exposure to the learning materials.

- Subject population

A problem in previous studies was the heterogeneity of the subject population. Thus the subject sample of this evaluation was exclusively drawn from a population of native English speakers that had no formal knowledge of the geology of Holyrood Park.

- Tutorial redesign

Previous tutorials were criticised for not being sufficiently relevant to the material in the actual experiment. Furthermore the information given was complex and uninformative. Thus, the tutorial was completely redesigned for the present experiments. Essentially the tutorial was made:

- more interactive
- more informative
- more intuitive

The tutorial was broken into three linked episodes. Each episode introduced additional features of the interface in a way that invited the user to practice what they were being shown in a sample virtual environment. Participants were free to use the tutorial until they were satisfied they understood how to navigate in the virtual environment. [see Appendix I-1-2 & the CDROM for screenshots of the tutorials]

- Tests redesign

In the previous studies several problems emerged in the data from some evaluation tests. The problems related to results contrary to what might have been expected. Only after all other theoretical explanations were ruled out was the validity of the tests questioned. It was eventually decided that some redesign of the tests was necessary to improve their validity. Changes made to the tests are described in the METHOD section.

- Improved observation

Previously subjects were unsupervised while participating on the computer version of the field-trip. If the subject experienced technical difficulties they referred to the online HELP area of the field-course. This was obscurely located and so was infrequently used. Consequently this was abandoned and the experiments all took place in a small training suite with the experimenter present throughout.

8.1.2.2 Changes to the technology

- Hardware & network access

Balancing the memory and bandwidth demands of the virtual field-trip was a constant challenge in previous experiments. Slow networks frequently led to the stalling or crashing of the virtual environment. In the present study all the experiments took place in a controlled environment where the experimenter was always present to help the participants if they experienced any difficulties.

- Bandwidth problems

Besides a slow unreliable network connection, problems were compounded in previous studies by the high bandwidth demands of the virtual environment. The two biggest consumers of bandwidth were the audio clips and the enhancement images used to bring higher quality detail to some panoramas. These files were therefore removed or their numbers reduced thereby increasing transmission speeds for the experiment.

8.1.2.3 Changes to the interface

- Interface modification

In previous experiments the interface design for both the VR and the MM versions was a source of great confusion and irritation. Previously, all user support information was built into an elaborate collection of web pages that were rarely used by subjects. The reason was that individuals were not certain of where to look for material such was the complexity of information they were required to remember. Much of the HELP material was put there to compensate for a poorly designed tutorial and interface. Additionally, the VR group was constrained from adequately learning the material due to interface complexity: subjects also did not know how to retrieve the maximum amount of information from the virtual environment. The solution was to remove the need for such complexity by:

a) creating a better quality tutorial section

b) redesigning the interface so that it was more intuitive, less cluttered and contained all the information required by the subject at the top level. This would have the effect of reducing on-screen complexity so that the subject could concentrate on what is to be learned.

All information was placed on the surface level of the interface where it was readily accessible to the user. The HELP section was removed and replaced both by a better quality tutorial and a real demonstrator. In addition, the icons and their function were continuously visible and available to the user.

- Structural changes to MM

In previous studies the Multimedia (MM) group performed consistently better at the ROUTE task than all other groups. The main reason for this was attributed to the use of a 'contents' section that was assumed to be being used as a mnemonic device by that group. To eliminate this possibility the 'contents' section was removed in the present version of the experiment, thereby making the MM version structurally similar to the VR version.

8.2 Method

8.2.1 Design

Design of the Experiment					
Virtual environment			Multimedia environment		
pedagogy		spatiality	pedagogy		spatiality
+meta / -spat	+meta / +spat	+spat / -meta	+meta / -spat	+meta / +spat	+spat / -meta
	-meta / -spat			-meta / -spat	

Table 8-1: Experimental design

As Table 8-1 illustrates, the experiment was a between-groups multifactorial design. There were two computer-based learning environments being evaluated: the virtual environment and the multimedia environment [see Appendices I-3-7 for screen-shots of both the multimedia and virtual reality environments; and the CDROM for sample environments]. On one level the experiment was a comparison of these two types of visualisation technology for their ability to enhance the learning process. Within each of these two groups are two levels: pedagogy and spatiality. Pedagogy refers to the influence of the specific tools and techniques derived from the eclectic approach to learning and teaching (chapter 2). Spatiality refers to the inclusion of spatial navigation and orientation features in the learning environment whose effectiveness is derived from the research on VENA's. Within each of these levels are the various cells of the design. These cells vary from inclusion of both pedagogic and spatial features for virtual and multimedia environments (+meta / +spat), which is essentially a test of the spatialisation of information theme, to the control groups (-meta / -spat) deprived of such features in both environments.

8.2.2 Subject profile

Ninety-six subjects participated in the present experiment (48 male and 48 female) with 12 subjects being assigned to each condition. Average age across all groups was 20.7 years. The subjects were mostly students from the University of Edinburgh who responded to adverts placed around campus. Of these 47.9% were studying science-based courses, 42.7% Arts / humanities-based courses and 9.4% were studying other subjects. Ninety-nine percent of subjects had been to Holyrood Park at least once and of these the average number of times that people had been was approximately seven. Two exceptions to this were the MMALL group (see Table 8-3) (13.4) and the MM (CTRL) group (13.7). Since subjects were randomly assigned to groups these exceptions were by chance alone. All subjects were paid volunteers.

8.2.3 Methods used

The evaluation methods used in this experiment included both qualitative and quantitative techniques examining performance at both process and outcome levels.

8.2.3.1 Pretests

- Paper-folding test (PFT)

The paper-folding test forms part of the spatial visualisation sub-scale of the Kit of Factor Referenced Cognitive Tests (Ekstrom et al., 1976). This is a six minute test consisting of 20 sets of drawings of a page that is folded and then has had a hole punched though it. Each set presents five alternative diagrams of a piece of paper that has been unfolded showing where the holes were produced when it was folded. Only one option has the correct pattern of holes and the subject's task is to choose the correct one in each case. The test was administered as a general indicator of spatial ability among the subjects. This information was used to establish that there were no inter-group differences in spatial ability that might jeopardise the validity of the other spatial tasks. Furthermore, subjects were classified as either high or low in spatial ability on the basis of their performance on the test. This test was chosen both for its ease of use and its predictive validity as noted by Anastasi (1988).

- Study Preference Questionnaire (SPQ)

This test developed by Ford (1985), refers to differences between how people approach different types of information classifying them either as serialists or holists in their thinking styles. The test consists of 18 pairs of statements describing alternate ways of approaching different information sources. One statement represents a serialist approach to the information while the other statement represents more of a holist approach. The subject is asked to choose between the statements by ticking a box indicating the degree to which they agree or disagree with each statement. The SPQ has been assessed for its validity in correlation analyses with Entwistle's 'Short Inventory of Approaches to Study' (Entwistle 1981). Several statement pairs were identified by Ford as most predictive and of these one was regarded as most predictive of the learning styles. This question is shown in Figure 8-1 for illustrative purposes:

1. When I'm reading a book (or other information source) for my studies, I prefer to spend quite a long time skimming over it to get a clear picture of what it's about and how it will be relevant.

2. When I'm reading a book (or other information source) for my studies, I prefer to get quite soon into a detailed reading of it once I know that it's going to be useful, in the knowledge that its precise relevance and contribution will become clear from a detailed reading

Please tick a box according to the response scale:

[ ] I agree with statement No.1
[ ] I agree (with reservations) with statement No.1
[ ] I agree with statement No.2
[ ] I agree (with reservations) with statement No.2

Figure 8-1: Sample statement from the Study Preference Questionnaire (Ford, 1985).

Subjects were therefore given this statement pair and asked to choose an appropriate box. On this basis subjects were classified as either serialist or holist in their approach to information.

8.2.3.2 Tests of spatial knowledge

- Landmark knowledge test X 3 [Appendix H-1]

The landmark test was modified. The main problem with the old test was it assumed that people developed landmark spatial knowledge according to the location of features. However landmarks may often be quite subtle and sometimes idiosyncratic features in the environment (e.g. Golledge, 1978, 1987; Lynch, 1960). Since the development of spatial knowledge in natural environments is not well documented in the literature, an exploratory test was designed. If a test examined what parts of the environment were most recognisable, this might suggest those areas the subject was beginning to treat as landmark-like features. Subjects were given three sets of 12 images taken from various points in the field-course environment. For each image subjects were required to provide two pieces of information:

1. Recognition: - do they recognise the visual features of the environment in the image?
2. Identification: - can they identify the name of the area in the image?

As a test that subjects were not just blindly guessing, some fake images were included which depicted places not found in Holyrood Park. Additionally, a comment box at the end of the test invited subjects to describe how they completed the task. This was included to gain an insight into the strategies that people used to solve this type of task.

- Route knowledge test [Appendix H-2]

The route test remained the same as in previous versions. The only change was an additional image to place in correct order. This was due to ceiling effects in previous evaluations.

- Survey knowledge test [Appendix H-3]

The test of survey spatial knowledge was also virtually unchanged from the previous evaluation. To ensure the subject was familiar with the two locations asked about in the test, an image of each location (or a picture of the geological feature) was included. The image also included the direction that the image was facing. Thus if the picture was of a feature and the angle of the picture suggested the camera was facing north then 'N' was superimposed on the image. This was in response to previous comments about not providing sufficient directional information to successfully complete the test. Marking of the test was also modified. Instead of receiving a single mark for choosing the correct direction, subjects received one point for choosing a direction next to the correct one and two marks if they were exactly correct. For example, if the correct direction was 'North', then 1 mark would still be given if the subject answered either 'North-east' or 'North-west'. This was to allow for degrees of accuracy that an all-or-nothing marking system would rule out.

8.2.3.3 Conceptual knowledge test [Appendix H-4]

The conceptual knowledge test was designed to examine the deeper level conceptual geological knowledge which subjects would have acquired from the field trip. There were no changes to this test.

8.2.3.4 Additional evaluation methods

- Questionnaire [Appendix H-5]

The questionnaire was shorter than other versions and the questions were more specific. A short summary of the different data points in the questionnaire included:

- age
- gender
- job / course
- number of times visited Holyrood Park
- enjoyment rating
- did they find the embedded feedback questions useful?
- did they find the spatial features useful?
- what did they use the location features for?

- Data-logging

This was potentially the most important source of data in the evaluation. Data-logs were created and time-stamped showing every electronic action by the subject while exploring Holyrood Park. The number of uses to which this data could be applied is shown below:

- number of times they saw an image of each geological feature
- number of times they saw descriptive text for each geological feature
- number of times they used the spatial features (e.g. aerial images)
- number of spatial features they used (which ones)

- number of times they used the glossary feature (and for how long)
- number of interactive feedback questions they attempted
- answers selected for feedback questions (and the order)
- how long they spent on different parts of the field-course
- the order in which they examined geological features (VR versions only)

The data provided a process-oriented account of how the subject went about learning the material. This is the eclectic idea of process-oriented evaluation where data from both outcome-based and process-based assessment combines to provide a richer profile of learning.

8.2.4 Procedure

Table 8-2 describes the order of events for each subject that partook in the experiment.

<table>
<tr><td>Pretest</td><td>Learning</td><td colspan="5">Evaluation</td></tr>
<tr><td rowspan="2">PFT
&
SPQ</td><td rowspan="2">Exploration
/ learning
of
environment

(1 hour)</td><td colspan="3">Spatial tests</td><td rowspan="2">Geological
knowledge
test</td><td rowspan="2">Questionnaire</td></tr>
<tr><td>Landmark</td><td>Route</td><td>Survey</td></tr>
</table>

Table 8-2: Order of events of experiment for each subject.

Upon entering the training suite each subject was randomly assigned to one of eight conditions. These conditions are described and labels assigned to them in Table 8-3:

Label	Reference above	Description
VRALL	+meta / +spat	VR with all spatial and learning features
VRSPAT	+spat / -meta	VR with spatial features only
VRMETA	+meta / -spat	VR with learning features only
VRCTRL	-meta / -spat	VR with no spatial or learning features
MMALL	+meta / +spat	MM with all spatial and learning features
MMSPAT	+spat / -meta	MM with spatial features only
MMMETA	+meta / -spat	MM with learning features only
MMCTRL	-meta / -spat	MM with no spatial or learning features

Table 8-3: Description of the eight conditions along with the labels assigned to them.

Once assigned to a condition, each subject received two pretests: the paper-folding test (PFT) and the Study Preference Questionnaire (SPQ). Both tests together took no more than 10 minutes to complete. Subjects were then directed to the computers that had been set up to display an introduction page to the experiment. The introduction page described general features of Holyrood Park and contained a hyper-link to a tutorial. Subjects were directed to go on to the tutorial in their own time. The tutorial differed between conditions.

Having completed the tutorials, the subjects were reminded by the experimenter of some minor technical issues to be aware of such as forgetting to close 'pop-up' windows. They were reminded that they had one hour to explore and learn about the geology of the environment and advised to navigate through it three times. Once the exploration and learning stage of the experiment were complete, the subject was directed to the evaluation section. There were five evaluation tests and a questionnaire. On average subjects took approximately 15 minutes to complete all the evaluation tests bringing the total amount of time spent on the experiment to approximately 90 minutes. All subjects were debriefed at the end of the experiment.

8.3 Results

A detailed presentation of results is given in Appendix E. The results below are described by test with the data for each test presented in three parts. The first part outlines the general results found for that test across all subjects and conditions. Though not very informative, it forms the basis upon which more detailed analysis may follow. Subjects themselves differed in both their uses of the learning environment and their individual cognitive styles. Both elements greatly affected many results. Thus, the second part of the analysis concentrates on subgroups characterised by their usage of the interface. This more detailed analysis is based on information from both the data-logs and the questionnaire and includes:

- number of times spatial features were accessed
- number of times meta-cognitive features were accessed
- number of previous visits to Holyrood Park

This more detailed analysis formed part of the overall assessment strategy of the eclectic approach to learning. Thus, process-based assessment was regarded as important as outcome-based approaches. Most important were the differences between the VR and MM groups on the use of spatial features (Table 8-4). The MM group used these features significantly more often than the VR group did. This was confirmed by a one-way Anova [$F(3,44)= 12.7$, $p<0.01$]. Post-hoc Scheffe tests found significant differences between VRALL and both MMALL and MMSPAT, and also VRSPAT and both MMALL and MMSPAT, all at a significance of at least $p<0.05$. Similarly LOW SPATIAL and SERIALIST subjects made more use of the spatial features than HI-SPATIAL HOLIST's though these differences were not significant.

	Mean	SD
VRALL	10	3.3
VRSPAT	11.8	8.4
MMALL	24.1	8.8
MMSPAT	23.5	7.3

Table 8-4: Use of spatial features by subjects from selected groups.

The number of times that spatial features were accessed by subjects from the VRALL, VRSPAT, MMALL and MMSPAT groups (the only groups to have such spatial features) was ranked. A median split (median = 16) divided them into HI-VENA (those subjects that accessed spatial features above the median number of times) and LOW-VENA (those subjects that accessed spatial features below the median number of times) subjects. The performance of each of these groups is examined below to examine how performance across the tests is affected by use of spatial features.

Subjects were also examined for how many interactive feedback questions they used. Again comparisons across groups in the use of meta-cognitive features revealed differences though none were significant. The number of times meta-cognitive features were accessed by subjects was ranked. A median split (median = 26.5) of the group divided the scores into HI-META (subjects that accessed meta-cognitive features above the median number of times) and LOW-META (subjects that accessed meta-cognitive features below the median number of times) subjects. The performance of these groups is also examined below for each test.

Subjects also differed in how often they had visited Holyrood Park. Subjects were asked to estimate the number of times that they had been to Holyrood Park. These estimates ranged from 'never' to those that had been there over 30 times. The mean number of times was 6.9. The frequency also differed across groups with the MMALL and the MM (CTRL) groups showing higher than average mean visits. To try to identify any confounds resulting from this imbalance, the frequency with which subjects visited Holyrood Park was also examined for each test. Again this was carried out using a median split of the data (median = 4) dividing the data into FREQ (those subjects that visited Holyrood Park above the median number of times) and INFREQ (those subjects that visited Holyrood Park below the median number of times) subjects.

Finally the third part of the analysis for each test was the analysis of individual cognitive differences. This is based on performance on the PFT and the SPQ.

8.3.1 Pre-tests

8.3.1.1 Paper-folding test (PFT)

No difference between groups was found for the PFT as expected. Mean score was 12.75. A one-way Anova confirmed this. A significant difference between males and females was found [$t(94)=2.81$, $p<0.01$]. Subjects were classified as either high or low in spatial ability (hi- / low-spatial) depending on whether they scored above or below the median (12.8) respectively.

8.3.1.2 Study Preference Questionnaire (SPQ)

Based on their performance on the SPQ subjects were classified as either serialists or holists. This resulted in a split among the subjects of 44 holists (45.8%) and 52 serialists (54.2%). Though not controlled for, the distribution of this cognitive style was split approximately evenly across the groups except for the MMMETA group that had two holists to ten serialists.

8.3.2 Landmark knowledge task

8.3.2.1 General analysis

Results from the three versions of the landmark knowledge test were combined and the accumulated means were analysed for the recognition score (whether the subject recognised the image from the field-trip) and the identification score (whether the subject could identify the name of the location displayed in the image). In addition to this a COMBINED score was calculated (the addition of the RECOGNITION and IDENTIFICATION scores). A comparison of means across all conditions for each of these three analyses found significant differences in favour of the VR groups [$F(7,88) = 5.15$, $p<0.01$] (COMBINED), while an independent-groups t-test between VR and MM confirmed this [$t(94) = 5.45$, $p<0.01$] (COMBINED). This difference was most acute for the RECOGNITION part of the test rather than the IDENTIFICATION stage.

8.3.2.2 Subgroup analysis

As described above, results for this as for all other tests were subjected to a subgroup analysis examining in more detail the:

1. number of times spatial features were accessed
2. number of times meta-cognitive features were accessed
3. number of previous visits to Holyrood Park

- Virtual environment navigation aids (VENA) usage

For both the HI- and LOW-VENA subjects, the VR groups outperformed the MM groups on the test of landmark knowledge. This applied to performance on both the recognition and the identification of locations from the geology field-course. However, only the HI-VENA group were significant with one-way anovas showing significant differences between the VRSPAT group and the MMALL and MMSPAT groups [$F(2,21) = 5.03$, $p<0.05$]. This result was based on performance in the IDENTIFICATION part of the Landmark test [$F(2,21) = 4.96$, $p<0.05$].

- Meta-cognitive questions usage

Differences between the VR groups and the MM groups on the use of meta-cognitive questions were more impressive than that for spatial features. Figure 8-2 illustrates these differences below. Two trends immediately become clear from the graph. The first is the dominance of the VR groups over the MM groups. This follows the pattern identified above for the VENA use analysis. The second trend is the general dominance of the VRMETA group. In every comparison made for both the HI- and the LOW-META groups, the VRMETA condition produces the largest result. Another trend is the general dominance of the HI-META group over their LOW-META counterparts. Though still apparent, this trend was less marked for performance on the use of VENA's by subjects. The differences between the groups were confirmed by a series of one-way anovas. They found a significant difference between the VRMETA and the MMALL groups for the HI-META subjects across the COMBINED [$F(3,20) = 5.28$, $p<0.01$], RECOGNITION [$F(3,20) = 3.89$, $p<0.05$] and IDENTIFICATION [$F(3,20) = 4.23$, $p<0.05$] portions of the landmark test. Among the LOW-META subjects the differences across conditions appear to have been greater. One-way anovas revealing significant differences for the COMBINED data between VRMETA and both MMALL and MMMETA [$F(3,20) = 5.56$, $p<0.01$]. The source of this difference was from performance on the RECOGNITION [$F(3,20) = 4.81$, $p<0.05$] portion.

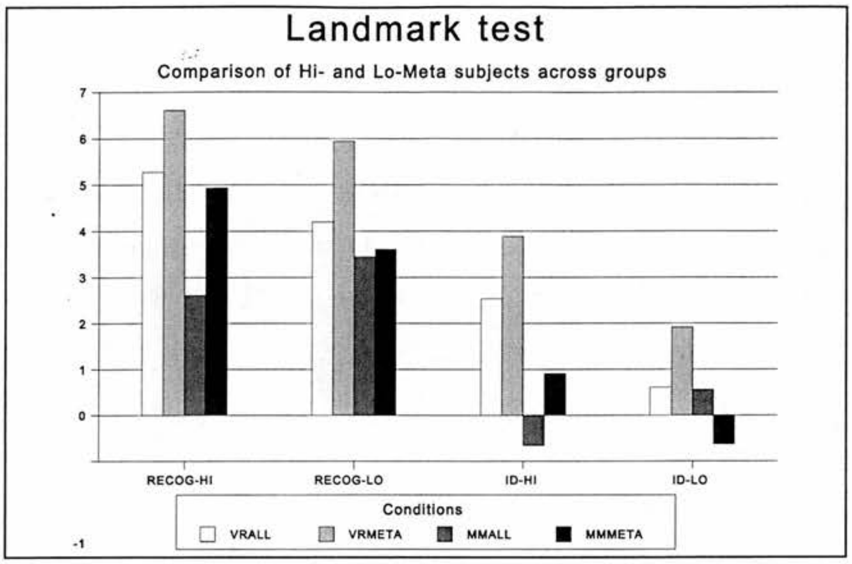

Figure 8-2: Comparison of HI- and LOW-META subjects across groups on Landmark test.

- Prior experience of Holyrood Park

Subjects who visited Holyrood Park frequently did slightly better than subjects who infrequently or had never been to the park though this was not significant. What was significant however were differences between the VR and MM groups. This held for both the HI-FREQ and LOW-FREQ subjects though were more pronounced for LOW-FREQ groups. Specifically for HI-FREQ RECOGNITION subjects there were significant differences between VRMETA and MMALL and MMSPAT [$F(7,40) = 3.73$, $p<0.01$]. However, among the LOFREQ group there were significant differences for all portions of the landmark test. For the RECOGNITION component the differences were between VRALL X MMALL, VRMETA X MMALL, VR X MMALL and VRMETA X MMSPAT [$F(7,40) = 4.59$, $p<0.01$]. On the IDENTIFICATION component the differences lay between MMSPAT and VRSPAT and VRMETA [$F(7,40) = 3.77$, $p<0.01$].

Generally the VRALL group did not perform as well as the VRMETA and VRSPAT groups on most portions of the test and for most groups of subjects. In one case among the LOW-FREQ group on the IDENTIFICATION test, the VRALL group did as well as the VRMETA group. Among the MM subjects the MM (CTRL) group did consistently better than its MM counterparts with performance on the MMMETA group following closely behind.

8.3.2.3 Analysis of individual differences

- High and low spatial

A three-way ANOVA found no significant differences between HI- AND LO-SPATIAL subjects across the different conditions of the experiment. However, within the HI-SPATIAL group there were significant differences between some conditions of the VR version and the MMALL condition of the MM group. This was verified with a one-way Anova [$F(7,40) = 4.8$, $p<0.01$]. Post-hoc comparisons using Tukey's HSD test ($\alpha = .05$), found these differences to reside between the following groups:

- VRSPAT X MMALL
- VRMETA X MMALL
- VR (CTRL) X MMALL

No other significant differences were found within the HI-SPAT group.

Among the LOW-SPAT group the differences were spread across all tests, however this was only significant between the VRMETA and the MMSPAT groups ($F(7,40) = 2.71$, $p<0.05$).

- Serialist / Holist

A three-way ANOVA found no significant differences between HOLIST and SERIALIST learners across all conditions of the experiment. Within the HOLIST learners however there were differences between the VR and MM groups for both the separate and combined analyses of the data. These were verified by anovas across the COMBINED data [$F(7,36) = 3.21$, $p<0.01$] which post-hoc tests revealed to lie between the VR(CTRL) and MMALL / MMSPAT conditions.

Among SERIALIST learners these differences were more numerous indicating greater variation among serialists depending on the technology used. This difference lay principally between the VRMETA group and all versions of the MM groups. A one-way Anova for COMBINED confirmed this result [$F(7,44) = 4.21$, $p<0.01$].

Finally a three-way ANOVA revealed a significant interaction effect between the various conditions of the experiment and HOLISTS and SERIALISTS: [$F(7,71) = 2.181$, $p<0.05$]. The nature of this interaction is illustrated in Figure 8-3:

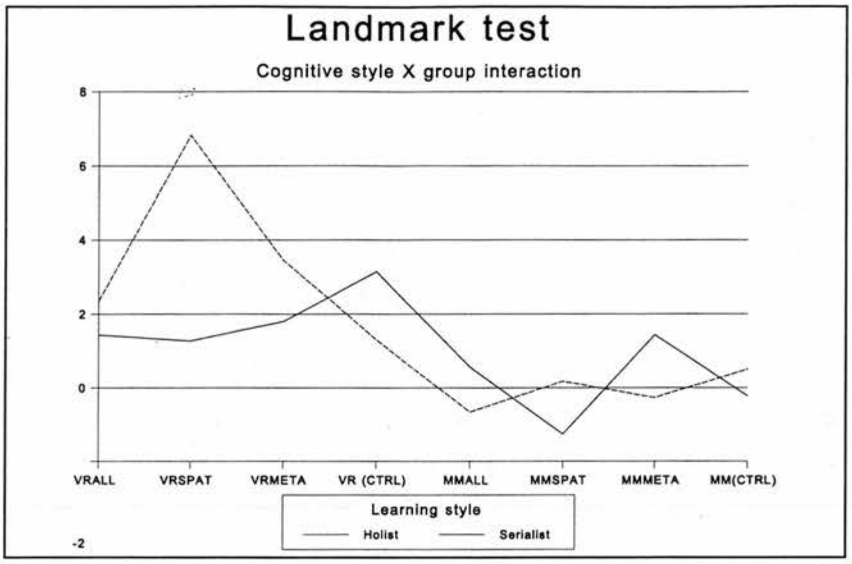

Figure 8-3: Interaction for Holist and Serialist learners on the Landmark test.

As shown in the Figure 8-3, VE's benefit HOLIST learners more than MM environments do (which by contrast, seem to convey no real advantage for either subgroup).

8.3.3 Route knowledge test

8.3.3.1 General analysis

Results for this test were corrected for guessing. A comparison of means across the conditions found no significant differences.

8.3.3.2 Subgroup analysis

- Virtual environment navigation aids (VENA) usage

Results were mixed and depended on the version of the field-course used (see Table 8-5). None of these differences were significant however.

	VRALL	VRSPAT	MMALL	MMSPAT
HI-VENA	n/a	6.68	6.94	4.68
LOW-VENA	5.23	6.01	6.01	6.01

Table 8-5: Performance of HI- and LOW-VENA subjects across groups on the Route test.

- Meta-cognitive questions usage

There was no significant difference in performance between HI- and LOW-META subjects across the groups (Table 8-6).

	VRALL	VRMETA	MMALL	MMMETA
HI-META	7.06	5.35	6.45	6.41
LOW-META	2.69	5.35	7.12	6.68

Table 8-6: Performance of HI- and LOW-META subjects across groups on the Route test.

- Prior experience of Holyrood Park

Performance of the LOW-FREQ group was greater than HI-FREQ across all conditions except VRSPAT (Table 8-7) though this was not significant. Performance for the MM groups was generally better than for VR groups.

	VRALL	VR SPAT	VR META	VR CTRL	MM ALL	MM SPAT	MM META	MM CTRL
HI-FREQ	4.24	6.68	3.68	3.35	5.68	4.68	5.92	4.40
LOW-FREQ	6.23	6.01	6.18	5.79	9.00	5.12	7.47	6.14

Table 8-7: Performance of HI- and LOW-FREQ subjects across groups on the Route test.

8.3.3.3 Individual differences

No significant differences were found between or within HI- and LOW-SPATIAL subjects or between SERIALIST and HOLIST individuals and no interactions.

8.3.4 Survey knowledge test

8.3.4.1 General analysis

Data for the Survey test was analysed both for subjects' egocentric direction score (EGO) and their geocentric directional estimate (GEO). A combined score (COMBINED) which was simply the sum of the EGO and GEO scores was also calculated. A comparison of means across the conditions of the experiment found no significant differences for each of these three estimates of survey knowledge (COMBINED= $F(7,88) = 0.82$, NS). Similarly grouped comparisons between VR and MM were also not significant.

8.3.4.2 Subgroup analysis

- Virtual environment navigation aids (VENA) usage

There were no significant differences between LO- and HI-VENA subjects across the conditions among the MM and VR groups.

- Meta-cognitive questions usage

Again none of the differences were significant between LO- and HI-META users.

- Prior experience of Holyrood Park

None of the differences were significant.

8.3.4.3 Individual differences

A significant difference between HOLIST and SERIALIST learners was found across the three estimates of survey knowledge for the VR group. This difference favoured the SERIALIST learners who consistently performed significantly better than their HOLIST counterparts. Independent t-tests confirmed this difference [COMBINED = $t(46) = -3.35$, $p<0.01$]. This is illustrated in Figure 8-4. While no significant difference across conditions was found for the SERIALIST learners, performance among HOLIST subjects was significantly different [$F(7,36) = 3.63$, $p<0.01$] though only in the COMBINED analysis.

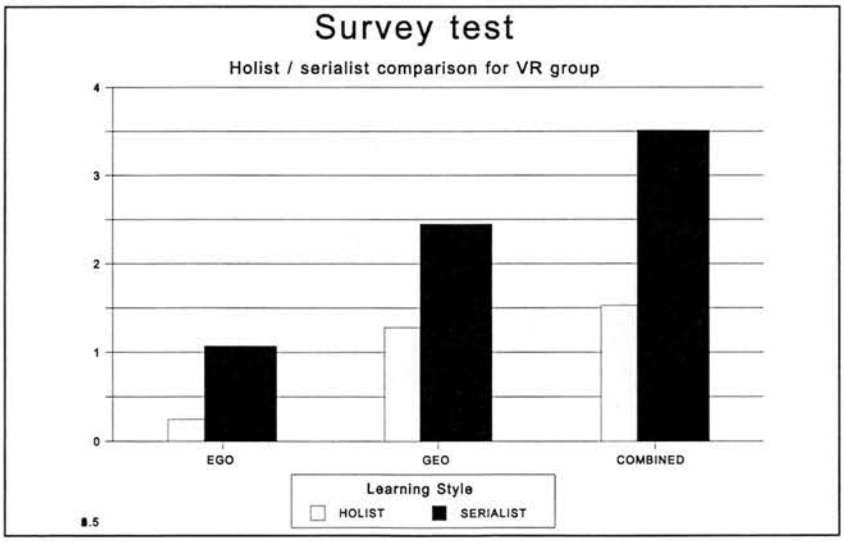

Figure 8-4: Differences between Holist and Serialist VR learners on Survey test.

Post-hoc tests revealed these differences to lie between the MMALL group and the VRSPAT, VRMETA, VR (CTRL) and MMMETA groups all of which were significant at $\alpha=0.05$. No such differences were found for the HI- / LOW-SPATIAL groups.

8.3.4.4 Interactions

- COMBINED data / all conditions

A three-way ANOVA on the COMBINED data found significant interactions between condition x HOLIST / SERIALIST learners [$F(7,71) = 3.99$, $p<0.05$] where SERIALISTS did better than HOLISTS in VR but not in MM. Results for MM were mixed. This interaction is illustrated in Figure 8-5. This graph is also representative of the interaction reported between these two groups for the GEO data set below.

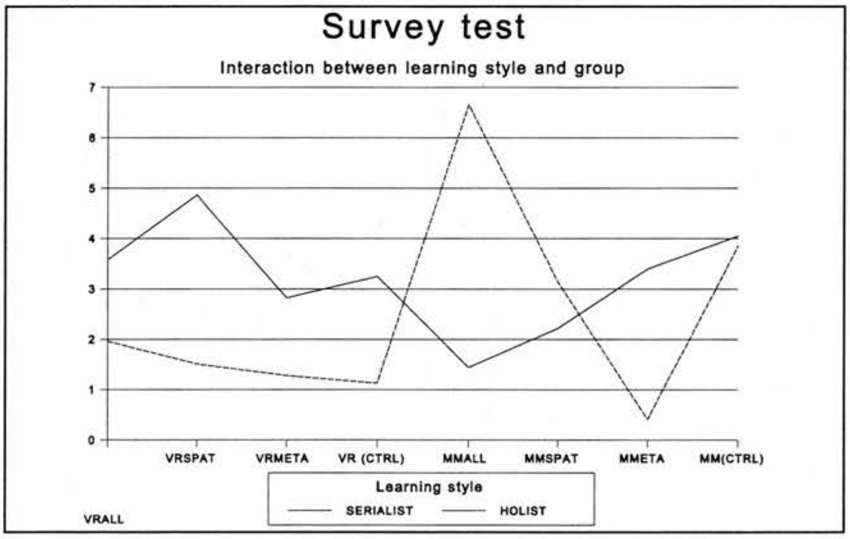

Figure 8-5: Interactions between learning style and group across the Survey test.

Similarly there was a significant interaction between spatial ability and style of processing [$F(1,71) = 5.59$, $p<0.05$]. Among HI-SPATIAL subjects, SERIALISTS did better than HOLISTS, this was reversed for LOW-SPATIAL subjects. This interaction is illustrated in Figure 8-6. This graph is representative of all other interactions between spatial ability and style of learning among subjects taking the survey test.

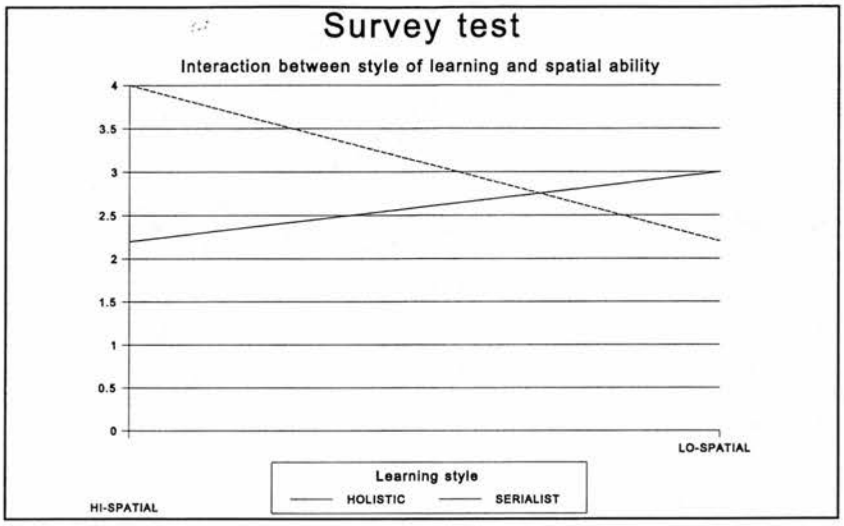

Figure 8-6: Interactions between learning style and spatial ability across the Survey test.

- EGO data / all conditions

For the EGO data there was an interaction between the conditions and spatial ability [F(7,71) = 2.17, p<0.05]. HI-SPATIAL subjects did better than LOW-SPATIAL subjects in MM but not in VR. Results for VR groups were mixed. This interaction is shown in Figure 8-7:

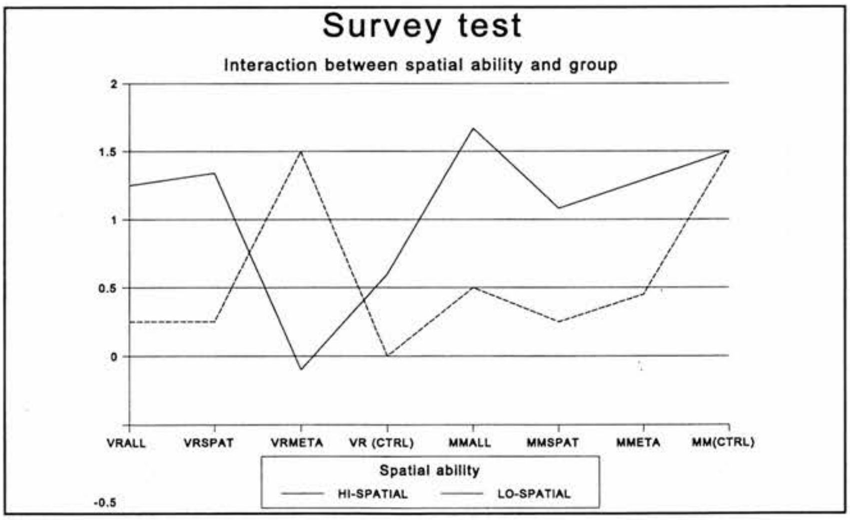

Figure 8-7: Interactions between spatial ability and condition across the Survey test.

- GEO data / all conditions

For the GEO data there were two interactions, one between condition and style of thinking

[F(7,71) = 2.44, p<0.05] and one between style of thinking and spatial ability [F(1,71) = 3.86, p<0.05]. In the first interaction SERIALISTS did better than HOLISTS in VR but not in MM. Results for MM were mixed. In the second interaction SERIALISTS did better than HOLISTS among HI-SPATIAL subjects. This was reversed for LOW-SPATIAL subjects. Results for MM were mixed. Further analysis within groups found additional interactions within the MM group. No such interactions were found for the VR group.

- COMBINED data / MM group

Here significant interactions were found between condition and style of thinking [F(3,35) = 7.28, p<0.01] with HOLISTS outperforming SERIALISTS for MMALL and MMSPAT groups. This was reversed for MMMETA and MM groups. This interaction is illustrated in Figure 8-8, and is also representative of the interaction between condition and style of thinking found for the GEO data-set and reported below. There was also an interaction between style of thinking and spatial ability [F(1,35) = 13.8, p<0.01] where among HI-SPATIAL subjects SERIALISTS perform better than HOLISTS. This was reversed for LOW-SPATIAL subjects.

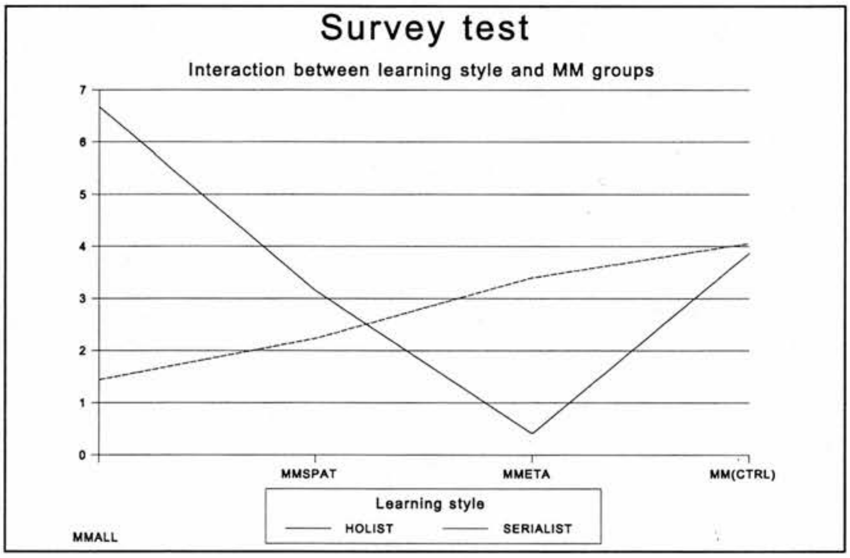

Figure 8-8: Interactions between learning style and MM groups across the Survey test.

- EGO data / MM group

Style of thinking interacted with spatial ability [F(1,35) = 5.03, p<0.05] where among HI-SPATIAL subjects SERIALISTS performed better than HOLISTS, while this was reversed for LOW-SPATIAL subjects.

- GEO data / MM group

Condition interacted with style of thinking [$F(3,35) = 4.36$, $p<0.01$] and style of thinking with spatial ability [$F(1,35) = 8.67$, $p<0.01$]. In the first interaction HOLISTS outperformed SERIALISTS for MMALL and MMSPAT groups, while this was reversed for MMMETA and MM groups. In the second interaction SERIALISTS performed better than HOLISTS among HI-SPATIAL subjects. This was reversed among LOW-SPATIAL subjects.

8.3.5 Conceptual knowledge test

8.3.5.1 General analysis

Data for the test of geological conceptual knowledge was corrected for guessing before being compared across the conditions of the experiment. No significant differences were found.

8.3.5.2 Subgroup analysis

- Virtual environment navigation aids (VENA) usage

VR groups outperform the MM groups for both the LOW- and HI-VENA subjects. There were insufficient subjects to provide data for the HI-VENA VRALL group. Across VRSPAT, MMALL, and MMSPAT groups, HI-VENA subjects outperformed LOW-VENA's and for VRSPAT this difference was significant [$t(34)= 2.08$, $p<0.05$].

Of most interest was a comparison across conditions for VR subjects between HI- and LO-VENA groups (see Figure 8-9). The most interesting thing about this chart is the peak for the VRSPAT group. Compared to the VRMETA group it was approaching significance [$t(14)= 2.03$, $P=0.062$]. This shows that the inclusion of spatial features enhanced performance on the test of conceptual knowledge to a greater degree than the inclusion of meta-cognitive features. However the VRMETA group were not controlled for those that used the meta-cognitive features frequently (HIMETA) and infrequently (LOMETA). When such information was controlled for, a non-significant result emerged although the means of the two groups were identical to those above [$t(8)= 1.79$, $p=0.111$, NS]. Nonetheless the result is still important in showing the effectiveness of spatial features for enhancing learning of non-spatial material. Unfortunately there were no HIVENA VRALL subjects available to compare with those of the VRALL LOVENA and the other conditions.

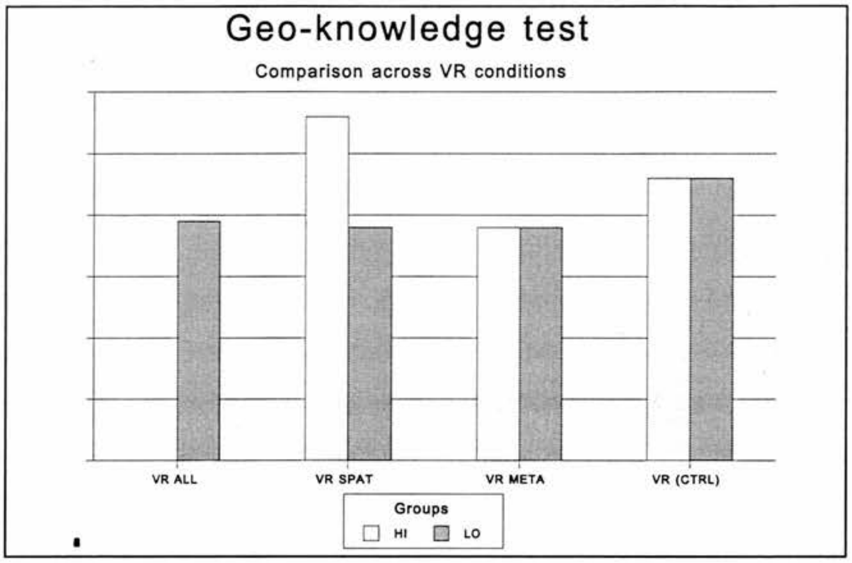

Figure 8-9: Performance of HI- and LOW-VENA subjects for VR groups on Geo-knowledge test.

- Meta-cognitive questions usage

Analysis of the meta-cognitive usage data revealed no differences across or within groups. Results were very similar with a very slight bias in favour of the MM group and the HI-META subjects. No differences were significant.

- Prior experience of Holyrood Park

There were no significant differences for HI- and LO-FREQ groups across conditions.

8.3.5.3 Individual differences

No significant individual differences were found between or within groups. There was a slight interaction approaching significance between condition and spatial ability[$F(7, 71) = 2.06$, $p=.059$]. This suggested that HI-SPATIAL subjects in the VRMETA, VR, MMMETA, MM groups do better than LOW-SPATIAL subjects on this test while LOW-SPATIAL subjects in the VRALL, VRSPAT, MMALL, MMSPAT groups do slightly better than their HI-SPATIAL counterparts.

8.3.6 Usability and qualitative results

From the questionnaire, subjects were asked to rate the degree to which they found the virtual field excursion enjoyable. The rating scale was from one (not enjoyable) to five (very enjoyable) and the results across all conditions are shown in Figure 8-10. Despite the similarity of the ratings the VRALL condition was rated as the most enjoyable version of the field-course while the VRMETA version was rated the least enjoyable.

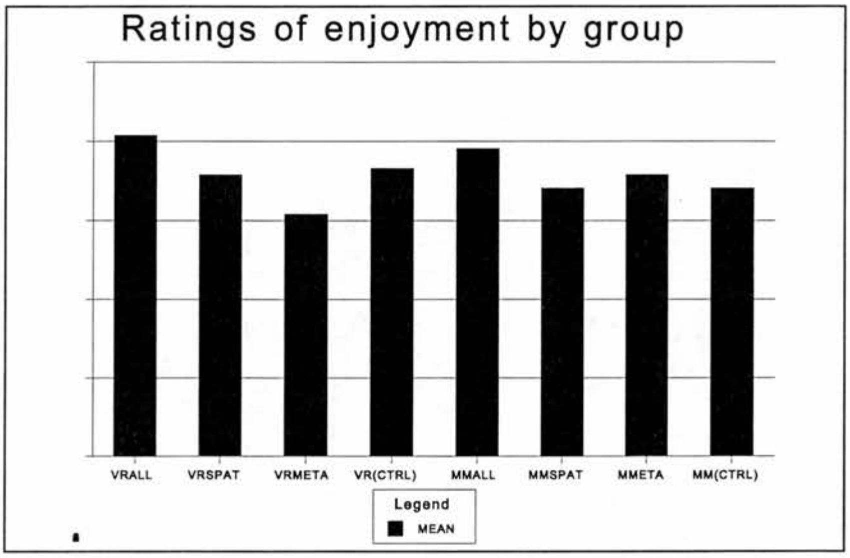

Figure 8-10: Ratings of enjoyment for each of the field-course versions.

8.4 Discussion

Given the results above are reported on a test by test basis, it is not obvious whether the various hypotheses in the experiment have been supported. This section clarifies this by discussing the results thematically. What emerges is a quite complex picture of human interaction with computer-based learning environments. To simplify the interpretation of results, the significant findings are presented thematically in Appendix E-1.

8.4.1 Affordances by virtual environments of spatial information

This theme predicted that inclusion of spatial aids should enhance performance over conditions that did not have them. Furthermore it predicted that the spatial versions of the VR field-trip should show superior performance over those from the MM version. This related to the inherently spatial characteristics of the virtual environment. The first hypothesis was not supported by the experiment. There were no instances of spatial conditions among VR versions outperforming CTRL conditions within that group. This is disappointing since it indicates that within VR the addition of spatial navigation aids had no significant effect on performance across spatial and non-spatial tasks. The same was also true for the MM group though there was an exception to this among high users of navigation aids where subjects on the MMSPAT condition of the Landmark and Survey tests outperformed those in the MMCTRL condition.

By contrast the second hypothesis was widely supported across the Landmark test. This hypothesis assumed that the inherent spatial characteristics or affordances of virtual environments would lead to greater improvements on spatial tests than for MM versions. Thus instances where the VRSPAT and VRCTRL groups outperformed the MM groups would be support for this hypothesis. Across all versions of the Landmark test and for all types of individuals, these VR conditions outperformed their MM counterparts. Thus the superiority of the VRSPAT group over their MM versions supports the idea that inclusion of navigation aids in VR environments leads to superior performance over MM versions with and without such aids. This leads to the inference that some additional aspect of the spatial structure of a desktop VR environment must contribute to this enhanced performance. This idea is further supported by the finding of so many instances of VRCTRL conditions outperforming all MM conditions on this test. Thus the inherent spatio-structural features of a VR environment are enough to lead to improvements on certain tests of spatial knowledge. This is a key element of the 'affordances' theme.

The results of these two hypotheses support each other. The absence of significant findings on the first hypotheses can be explained by the reasons given for the support of the second one. In other words, the strength of the spatial affordances of virtual environments are perhaps more influential in affecting performance on the spatial tests than the inclusion of navigation aids. This may have the effect of generally enhancing performance over all the VR versions of the field-trip so that more subtle differences due to the presence of the spatial aids are not observed. However this cannot be the only reason since a similar finding (though not as strong) was found for the MM versions. Thus it is also possibly the case that the spatial navigation aids were not presented in such a way as to achieve the maximum amount of effectiveness. For example, one of the changes made from previous evaluations was that the selection and use of navigation aids was made optional even though the subjects were strongly encouraged to use them. This was a necessary change since the automatic presentation of maps and aerial images previously had led to a slower down-load rate. Thus the spatial features may not have made the same impact upon students' learning as they might had their presentation been automatic.

8.4.2 Spatialisation of information

Spatialisation of information is the enhancement to memory and learning of information whose spatial and non-spatial components are presented conjointly. Both VRALL and MMALL conditions incorporated this feature into their structure. It was expected that these versions would lead to more enhanced performance on both the spatial and conceptual knowledge tasks than for any other condition in the experiment. Furthermore, given the affordances of virtual environments for presenting spatial information, it was expected that this enhancement should be stronger for the VRALL condition than MMALL.

In relation to the first hypothesis, there were no within-group differences between the VRALL condition and other VR conditions across any of the tests. Among the MM groups, MMALL outperformed MMMETA on the COMBINED analysis of the Survey spatial test among HOLISTIC subjects. For the second hypothesis, which predicted differences between VR and MM groups, results were test-dependent. On the Survey test for HOLISTIC subjects MMALL outperformed VRSPAT, VRMETA and VRCTRL. However on the Landmark test, VRALL outperformed MMSPAT and MMALL groups. Thus in general while there was some support for the spatialisation of information hypothesis, this was mixed and dependent upon the test taken.

The most likely explanation for the poor results is that the correspondence between presentation of spatial information and semantic information was not sufficiently controlled. Subjects were presented with map-like images of the park and the geological features in it. However, the subject had to open such maps by clicking on a button. Though instructed to do so at every possible opportunity, invariably many subjects did not always use the images as advised. Additionally the order in which subjects viewed maps concerning the semantic information was not controlled. This is something that previous research found important for contributing to conjoint retention. The reason the map image presentation was not controlled was due to the problems associated with automatic presentation of map-like images described in previous experiments. Additionally, while the spatial characteristics of the VE were expected to further enhance the spatialisation of information, it is suspected that the correspondence between semantic and spatial information was not made sufficiently explicit. The lesson for future evaluations is to ensure tighter correspondence between the presentation of spatial and semantic information in a virtual environment. If this includes the automatic presentation of spatial information then measures need to be taken to reduce the bandwidth problems associated with downloading large files.

One other issue relates to the composition of the VRALL group in the comparison above. While the content of the MM groups is adequate (containing equal numbers of HI-VENA and HIMETA subjects), the VRALL group contains subjects that did not use the spatial features very often (e.g. LOVENA). This places the VRALL group at a disadvantage. Furthermore, given the composition of the control groups, there was no way of controlling for their use of spatial or meta-cognitive information.

8.4.3 Eclectic pedagogic approach

The eclectic approach to learning emphasises the importance of meta-cognitive information, extrapolation from the information and the inclusion of goal-directed but exploratory learning in a flexible environment. It was predicted that the implementation of these learning principles should benefit those conditions that contained them (-META) in contrast to control groups. Furthermore, as with the affordance hypothesis it was also predicted that VR groups containing the eclectic aids should outperform MM groups due to the characteristics of virtual environments that enable such learning features to be incorporated into their structure more seamlessly than MM groups. They also enable aids to be presented more effectively.

The first hypothesis was not supported across any test for any group. Thus inclusion of eclectic learning features through the VRMETA or MMMETA groups does not enhance learning within VR and MM versions respectively. This was similar to the result for affordances and the spatialisation of information hypothesis. However the second hypothesis was widely supported across most comparisons for the landmark test. Thus inclusion of eclectic learning features in VR versions led to greater improvements across the landmark knowledge test than the inclusion of the same features in the MM versions of the field-trip. This implies that there are certain qualities of the structure of desktop VE's that allow inclusion of eclectic features to improve learning to a greater extent than for MM. This is interpreted in the current research as relating to the reifying qualities of virtual environments.

The poor support for the first hypothesis may again be the case that the inherent structural characteristics of the desktop VE's that resulted in support for the second hypothesis overwhelmed any more subtle effects of the eclectic learning features within each group. Again, this would not suffice for the performance of the MM group. Thus it is most likely that the effects of such features were not powerful enough on their own to influence performance across either the spatial or non-spatial tests within each group. This may be partly due to the way such features were presented to subjects. As with the spatial features the meta-cognitive features were not used consistently by all subjects. Indeed some subjects used them more than others. Unlike the spatial features, they were automatically presented though were located in a somewhat obscure area in the interface. It is possible that more consistent use of the eclectic learning features such as the interactive feedback questions might have resulted in improvements. Support for this suggestion comes from the differential performance of the high and low users of such meta-cognitive features with high users performing slightly better across all spatial tests in VR. Though this result is not significant it serves to indicate the complexity of interaction involved when attempting to derive a positive learning outcome from the intervention of a mechanism for learning.

Overall, these results are partly supportive of the hypotheses relating to the effectiveness of the eclectic methodology and the suitability of virtual environments for incorporating them.

8.4.4 Role of individual differences

Individual differences dominated this chapter and were incorporated into the results section where individual differences were described for:

- high and low spatial subjects
- holist and serialist subjects
- high and low users of spatial features
- high and low users of meta-cognitive features and
- frequent and infrequent visitors to Holyrood Park.

The first two differences were described as relevant to the experiment from the outset and represented differences in cognitive style. It was hypothesised that these cognitive differences may affect performance across tests depending on the version of the geology field-course that those groups used. The third and fourth set of differences arose from motivational variation between subjects when participating in the experiment. Finally the difference in frequency of visiting Holyrood Park was thought a possible confounding variable and thus was analysed to control for it.

8.4.4.1 High and low spatial subjects

While there were no direct differences between high- and low-spatial subjects, there were many within-group differences particularly on the Landmark test. Additionally from these comparisons, the trend that emerges is that the VR version of the field-course supported both high- and low-spatial subjects to a far greater extent than the MM versions. One prediction that was not confirmed was the greater support of the low-spatial subjects by the VR version. What is noticeable is that among low-spatial subjects, only VRMETA outperformed MM groups whereas for the high-spatial subjects, performance was superior across the VRSPAT, VRMETA and VRCTRL conditions. This leads to the conclusion that it was the combination of the inherently spatial structural elements of VE's along with the inclusion of eclectic learning aids that aided low-spatial subjects in their performance. Though they most likely attempted to adopt a non-spatial problem solving strategy, the VE was better able to support this strategy due to its spatio-structural characteristics.

The interaction between spatial ability and performance on the test of conceptual geological knowledge was not something that was predicted since it was assumed that spatial ability would not interact to any great extent. However this was not the case. An interaction among serialist subjects with performance on this test found that HI-SPATIAL subjects in the VRMETA, VR, MMMETA and MM groups performed better than LO-SPATIAL subjects on this test, while LO-SPATIAL subjects in the VRALL, VRSPAT, MMALL and MMSPAT groups performed slightly better than their HISPATIAL counterparts. This finding is interesting since it contrasts with performance on the landmark test. Generally, low-spatial subjects are finding the spatial version of both the VR and MM field-trips to be most beneficial for performance on the conceptual knowledge test while hi-spatial subjects are finding that versions with a distinct absence of spatial aids are most effective.

8.4.4.2 Holist and serialist subjects

Differences in learners' approaches to information had a major impact on performance across the tests and for different groups of subjects. In addition there were many interactions between style of learning and spatial ability. It was predicted in the hypotheses that serialists would find the linear structure of the MM version more beneficial for learning while the holists would prefer using the VR version of the field-course. However, this was not the case. Generally, holist subjects were better supported by the VRCTRL condition on the landmark test than MM versions but on the survey test they performed better on MMALL conditions over VR versions. These mixed findings were clarified by an interaction effect for version of the field-course by learning style which found that VE's benefited holist learners more than do MM environments (which seem to convey no real advantage for either subgroup).

By contrast, serialist subjects were consistently supported by the VR conditions, particularly the VRMETA version of the field trip on the landmark test with performance against all versions of the MM environment being significant. This was confirmed by a number of interactions on the survey test with one in particular finding that SERIALISTS performed better than HOLISTS in VR but not in MM (which was mixed). However this group was investigated further and found that HOLISTS outperformed SERIALISTS for MMALL and MMSPAT groups, but that this was reversed for MMMETA and MMCTRL groups.

One other finding of note among learning style differences were the interactions between learning style and spatial ability particularly on the survey knowledge test. Specifically among HISPATIAL subjects, SERIALISTS performed better than HOLISTS, this was reversed for LO-SPATIAL subjects across both VR and MM versions of the field-trip.

Thus in general, the serialist subjects benefited most from the structure of the virtual environment especially when that environment was endowed with spatial and meta-cognitive information. The structure possibly made more sense to serialists since it was tied to the real world spatio-structural characteristics of Holyrood Park. This was not so for the MM version. No consistent pattern of results emerged from MM. However, the inclusion of the meta-cognitive learning aids in the MM versions did appear to lead to a performance differential in favour of the holist subjects. In summary, the data on learning style suggests that serialist subjects performed better than their holist counterparts within the context of a virtual environment.

8.4.4.3 High and low users of spatial and meta-cognitive features

One development of the present research was the realisation that subjects differed in use of available spatial and meta-cognitive features. One unexpected finding was MM groups (MMALL, MMSPAT) had used such spatial features over twice as much as subjects in similar VR conditions. No such difference was noted for meta-cognitive features. One reason is that VR subjects possibly had less time to devote to the spatial features. Given the novelty factor associated with the virtual environment and the familiarity of the location, much of the subjects' time was spent browsing the panoramic views exploring the locations. An additional reason may have been wasted time spent waiting for scenes and images to load. However if limited time were the problem then one would expect a similar usage difference for meta-cognitive aids but there was none. Thus the difference may have been the layout of the interface and the position of the aerial images (see section on usability below).

Motivational differences among subjects may also have been a factor behind the differential use of spatial and meta-cognitive aids. If motivation were the reason then one would expect a high correlation between use of one aid with use of another. However there was no significant correlation between meta-cognitive features use and the use of spatial features [r(24)= -.2225, NS] and if anything the relationship was a negative one. This latter finding is an interesting one since it suggests that the more subjects used one type of aid, the less likely they were to use the other type. Thus, either time constraints or learning style preferences led people to concentrate more on one type of aid over another. However, no correlations were found for use of aids and cognitive styles.

While no direct differences between high and low users of spatial aids were found, the differences within each of these groups were of interest. For high users of spatial aids, the VRSPAT condition resulted in significantly better performance on the landmark knowledge test over MMALL and MMSPAT versions. Within the MM groups performance for the MMSPAT subjects was significantly better than MMCTRL for both the landmark and survey tests. No such differences were found for the low users of spatial aids. These findings clarify the results on the affordances hypothesis reported above. They imply that among the VR groups, part of the reason no differences between spatial and non-spatial groups was apparent was due to lack of differentiation between the conditions on the inclusion or otherwise of spatial navigation aids. However something other than those aids must have contributed to the superior performance of the VRSPAT group over the MMALL and MMSPAT groups. What is most likely is that the combination of the spatial navigation aids in the context of the spatio-structural features of the virtual environment combined to produce superior performance over the MM conditions. This strongly supports the affordances hypothesis.

Without exception the VRMETA version of the field-trip benefited both high and low-users of meta-cognitive features equally, relative to MMALL and MMMETA versions of the MM field-trip. This was evident across the landmark test. These results further support the findings for the eclectic learning features hypothesis by showing that while differences within the VR and MM group were not sufficient to be significant, differences between these groups were. Thus the combination of the eclectic learning features *with* the unique spatio-structural characteristics of VE's that allows them to seamlessly incorporate such features produce learning gains over those associated with the MM versions of the field-course.

The differences here between high and low users of spatial and meta-cognitive aids were most likely a factor in previous evaluations. Because no significant data-logs were produced however, it is impossible to re-analyse the data. Indeed it is a vindication of the process-based approach to evaluation and assessment that these factors were highlighted and the data re-analysed in response to them.

8.4.4.4 Frequent and infrequent visitors to Holyrood Park

Performance across the landmark test among all versions of the VR field-trip was superior to MMSPAT and MMALL versions of the MM field-trip for both low and high frequency visitors to Holyrood Park. However, performance was more differentiated between VR and MM among the low frequency visitors than for the high-frequency ones implying that VR benefitted the low frequency visitors to a greater extent.

Subjects that had visited Holyrood Park many times may have relied on their prior knowledge and experience in the evaluation tests. The spatial representation acquired from the virtual field-course may not have corresponded completely with their prior knowledge (e.g. distortions, see chapter 3). This may have led to conflicting spatial representations and therefore to poorer performance on the spatial evaluation tests. Similarly, poorer performance on the knowledge test may have been a secondary effect of this difference in representations.

In general, the individual differences reported in this experiment provided a rich seam of information. Some of it was planned, while other differences emerged as the data was analysed. This information should inform the design of future experiments where motivation and usability besides individual cognitive differences need to be accounted for.

8.4.5 Usability issues

The changes made to the interface and the technology paid dividends in this experiment. Very few problems were encountered with the VR versions and most subjects found the interface easy to use and navigate. Evidence for this comes from the enjoyment ratings illustrated in Figure 8-10, which show that ratings for the most complex VR version (VRALL) were higher than for any other condition. Indeed what problems did arise were typically due to inexperience with the WINDOWS interface than anything to do with the interface of the virtual environment.

However the experiment was not without its problems, the biggest of which were differential usage rates of spatial features among subjects. In particular MM groups used the features more than twice as much as their VR counterparts. The most likely reason was that the links to the spatial features in the VR version were poorly presented in the interface. The VR field-course was a split-screen interface. At the top was a 'window' onto the panoramic locations of Holyrood Park. Information in this window was linked to geological information in the bottom of the screen. That area contained links to spatial features followed by general information about the geology of the area. Below this, more detailed information was given and under that again was a meta-cognitive question. Given that the descriptive paragraph was most important, it is possible that many subjects went directly to this without clicking on the spatial feature links above it. Once the subject had scrolled to the detailed information, the section of the web page containing the spatial link would have scrolled out of view. This would have increased the chances of it being forgotten by the subject.

The solution then is to place the link for spatial features at a location where it will not disappear off the screen when scrolling begins. One solution might be to include it in the descriptive paragraph perhaps immediately after the description of the geological feature. The subject could be invited to click on the spatial link to see where the feature they have just been reading about is found. This would also be more similar to the presentation format adopted by many researchers testing the conjoint retention of spatial and semantic information.

Comments on the evaluation

This evaluation was a successful one in that it achieved answers for all the questions it posed at the outset of the chapter. Improvements to the design led to a greater consensus across tests on the various factors being evaluated. The importance of a process-based approach was vindicated by the analysis of spatial and meta-cognitive features usage. However the vast body of data produced by the data-logs and time constraints precluded more detailed analyses. Improved data management techniques need to be incorporated into the programs written to process such data so that the information is not wasted. Additionally, the subject sample was not ideal. The most appropriate sample would have been first-year geology students though efforts to use this group were not successful.

8.5 Chapter summary

The conclusion from this chapter is that desktop virtual environments are effective learning tools for certain groups of individuals and certain types of information. Most aspects of the framework are supported by the data but not all. The exception is with the spatialisation of information theme but even here some elements of that theme are supported. Most of the major usability concerns are addressed and consequently enjoyment ratings for all versions of the field-course are very high. However, the overriding theme of this chapter is certainly the role of individual differences and their impact on the research. Of these differences, the most interesting are the ones that were not anticipated, and interactions among ones that were. Individual differences strike at the heart of every 'model' or 'framework' or 'approach' to learning and education that attempts to prescribe ready-made solutions to problems. This poses the painful question: is the current framework for learning any different?

9.

Consolidation of experimental data

In this chapter the experimental findings of the research from the previous three chapters are summarised under the main conceptual themes of the thesis. Consistencies in the research are highlighted and analysed for the degree of support they lend to those themes. This is followed by analysis of the research in relation to the predictions of the framework for learning.

9.1 Affordances by virtual environments of spatial information

This theme suggested that affordances in the structure of virtual environments would benefit the acquisition of spatial knowledge more than in a multimedia environment. Additionally the inclusion of spatial navigation features should benefit the acquisition of spatial knowledge.

9.1.1 Summary of research

A pilot evaluation of a geology field-course was carried out on the excursion to Siccar Point (experiment 1). Here two versions of the field-course were developed. Both made use of simple text and images to convey the information. In one case, additional spatial and conceptual aids were included while in the other version these aids were omitted. These included numbered geological features that could be related to their spatial location in the environment along with plate-setting and sketching animations. Evaluation tests were designed to assess the spatial knowledge that was acquired. These included tests of landmark, route and survey spatial knowledge. Results across spatial tests were generally positive with the experimental group doing significantly better than control on landmark knowledge. These results partly supported the effectiveness of spatial aids for learning spatial information.

Experiment two was the first test of the Holyrood Park virtual environment as constructed using Reality Studio technology. Three groups were compared: a VR group that used the virtual environment version of the field-course; a group that used a limited computer-based version incorporating text and static images (MM) and finally a control group that simply used a paper version of the field-course. The VR version incorporated the use of immersive panoramic scenes along with a selection of orientation, navigation and geology features. Results for the spatial tests broadly supported the view that the VR versions were better than MM or control for acquiring landmark knowledge and to a lesser extent survey knowledge. For route knowledge the MM version was more suitable.

The objective of experiment four was to test the effectiveness of the virtual environment for acquiring conceptual information without the effects of embedded feedback questions. The experiment was a replication of experiment two except that the questions were removed. Similar evaluation tests were administered to subjects. The VR group consistently did better than the control group (CTRL) across all of the spatial and knowledge-based tests (except Geo-knowledge). Performance against the MM group was superior except for the Route and Geo-knowledge tests.

The theme of spatial affordances continued in experiment six where analysis by individual differences allowed for a more detailed breakdown of results. While no within group differences were found, VR groups consistently outperformed their MM counterparts across conditions on the landmark test. This finding was further supported among high users of spatial features.

9.1.2 Analysis of hypotheses

Hypothesis 1: *Navigation aids enhance acquisition of spatial information.* This hypothesis was well supported in the early research of the thesis but was not supported in the final experiment. Possible reasons centre around a lack of differentiation between the conditions.

Hypothesis 2: *Navigation aids enhance learning of spatial information from virtual environments more than from multimedia environments.* This hypothesis was well supported through the research with every evaluation reporting generally superior performance for virtual environment groups over their multimedia counterparts on tests of spatial knowledge. The weakest evaluation in this regard was the first Holyrood Park field-trip where there were complicating factors due to the inclusion of non-native English speakers though even here support was reasonably strong. One amendment to this hypothesis should also be considered however: the possibility that such learning enhancements are also related to specific features of the interface design. Such secondary enhancement is always a possibility though it was beyond these experiments to differentiate between it and navigation features.

Hypothesis 3: *VR groups should outperform others on landmark knowledge tests.* This hypothesis was based on the greater anchorage of the geological features to their location in the environment. Thus it represented an example of how spatial characteristics of the virtual environment enhance the development of spatial knowledge. This hypothesis was strongly supported across all the evaluations.

Hypothesis 4: *Multimedia and control groups are expected to display better performance on tests of geo-centred survey knowledge than ego-centred knowledge. Virtual environment subjects are not expected to differ between either of these tests.* Navigation in virtual environments was described as contributing to more primary-level survey knowledge. On the spatial tests this was expected to result in similar performance on geo- and ego-centric tests of survey knowledge. In contrast multimedia and control groups were expected to perform better on just the geo-centric version. The only evaluation in which this hypothesis could be explicitly tested was the final Holyrood Park experiment. No significant support emerged for this hypothesis. Analysis of means showed that multimedia groups did perform better on tests of geo-centred survey knowledge but so too did virtual environment subjects. This suggested that the survey knowledge acquired was more like a secondary map-based representation than primary navigation-based survey knowledge.

To summarise, there was some support for the effectiveness of navigation aids in enhancing acquisition of spatial information. Furthermore, their effectiveness was much stronger in the context of a virtual environment, particularly for the acquisition of landmark spatial knowledge.

9.2 Eclectic pedagogic model / reification of learning

The eclectic approach to learning proposes a framework for designing pedagogic environments with a focus on what works rather than what should work by philosophical doctrine. The introduction of virtual learning environments adds a new dimension to the evaluation of this approach. Virtual environments are tools that allow information to be presented and manipulated in original ways. This phenomenon was labelled the reification of learning. This reflects the way that virtual environments can transform understanding of the world similar to how abstract information may be understood more concretely. Thus, incorporating features from eclectic learning should aid the acquisition of non-spatial information. Secondly, reification of learning would lead to the hypothesis that the virtual environment results in improved performance on tests of non-spatial geological information than for their MM counterparts.

9.2.1 Summary of research

In experiment two several eclectic learning features were included in the learning environments. These consisted of: embedded feedback questions, presentation of information from different perspectives, use of goal-structuring techniques, process-based evaluation, presenting information in its appropriate context and allowing the user to control and actively interact with the information. While performance by the VR group was poor on the feature names test, performance on the conceptual knowledge test was superior across all three stages of testing. However, the latter result was later found to be primarily due to the inclusion of embedded feedback questions among the VR group.

A partial replication (experiment 4) of the first Holyrood Park evaluation without the embedded feedback questions, found that the VR group performed no better than control on the conceptual knowledge test. This suggested that the eclectic learning features were most useful for the acquisition of surface-level geological knowledge. By implication, the embedded feedback questions were more effective at enhancing deeper conceptual learning. However the degree to which the reification of learning was additionally important to the acquisition of this non-spatial knowledge was not certain. In experiment six this question was finally resolved. High and low VR users of meta-cognitive features did better than MM groups across the landmark test. Thus, application of an eclectic pedagogic approach did result in improved performance in particular for high users of eclectic learning aids using the VR version of the field-course.

9.2.2 Analysis of hypotheses

Hypothesis 1: *Eclectic learning features should enhance learning more than without them.* Support was found for this hypothesis in experiments 2 and 4. However this trend was not evident in the final evaluation with no significant difference between versions with eclectic features and those without them.

Hypothesis 2: *Eclectic learning features should enhance learning more in VR over non-VR environments (e.g. MM).* The only explicit test of this hypothesis occurred in the final evaluation. There learning using eclectic features among VR groups led to better performance on tests of landmark knowledge than for the MM group. This was interpreted as indirect evidence for the reification of learning mechanisms.

In summary, the results partly supported the principles underlying the eclectic learning approach. The features developed under the approach resulted in consistent enhancements to learning of non-spatial information. This supports a more pragmatic approach to learning and assessment. Furthermore the idea that virtual environments could further enhance the acquisition of non-spatial information was also supported by the research.

9.3 Spatialisation of information

This theme was concerned with how spatial and non-spatial information might be integrated in memory and the benefits for learning that might result.

9.3.1 Summary of research

In experiment two, a series of correlations pointed towards a relationship between performance on route and landmark tests with tests of geological knowledge. For the feature-naming test, this correlation was significant. Such findings merely suggest some support for the possibility of an interaction between spatial and non-spatial knowledge structures for task performance.

Experiment five was a direct test of the conjoint retention hypothesis for paper-based learning environments. It found improved memory for the information that was conjointly presented. This lent further support for the possibility that similar interactions might be occurring in the learning from the virtual field-course. An explicit test of this hypothesis was incorporated into experiment six however results were mixed.

9.3.2 Analysis of hypotheses

Hypothesis 1: *Conjoint presentation of spatial and non-spatial information enhances learning for that information more than for information not conjointly learned.* Only limited indirect support was found for this hypothesis.

Hypothesis 2: *Enhancements to learning from conjoint presentation should be greater in VR.* Spatial affordances of the virtual environment combined with the ability to reify non-spatial information were expected to lead to more enhanced learning than that experienced by MM groups. However, this was only the case on the landmark knowledge test of experiment six. Therefore, this hypothesis was not broadly supported by the tests.

In summary, limited, indirect support was found for the spatialisation of information theme. The fact that spatialisation of information can and does occur is not in question. Both the background literature and experiment five fully support the idea. The solution lies in a computer-based learning environment that encourages the development of spatialisation strategies to better aid the acquisition of spatial and non-spatial information.

9.4 Role of individual differences

9.4.1 Summary of research

In the Siccar Point field-trip differential effects were recorded among groups across the spatial tests. The results suggested modest support in favour of low-spatial subjects for conditions in which additional spatial features were provided. Unlike Siccar Point, experiment two favoured high-spatial subjects and this was found across all spatial tests except for low-spatial MM subjects on the survey test. However the difference between the low and high spatial groups for the VR condition was smaller for the landmark and route tests than for the MM or control group. This suggested VR support for low spatial subjects. Additionally low-spatial VR subjects outperformed the high-spatials on non-spatial tests. Unforeseen individual differences were an issue with the observation that non-native English speakers consistently under-performed on all of the spatial and geological tests.

In experiment four the trend favouring high-spatial subjects continued with superior performance for these subjects across both the spatial and non-spatial evaluation tasks. However, the low-spatial subjects for the VR group bucked this trend by outperforming their high-spatial counterparts on the landmark test. This also occurred for the MM group on the Route test and the control group on the survey test. When data was collapsed and normalised the trend again favoured high-spatial subjects across all spatial and non-spatial tests. However the difference between the high and low spatial subjects was smaller for the VR group than for any other group. This again suggested that the VR version supported low-spatial learners more than the other versions of the field-course. Findings were somewhat different in experiment six. There both high- and low-spatial subjects in those conditions that contained either spatial or eclectic learning aids were best supported in their learning of the material. Additionally, interactions between spatial ability and performance on tests of conceptual knowledge were found. Serialist subjects benefitted most from the structure of the virtual environment especially when that environment was endowed with spatial and meta-cognitive information. The inclusion of spatial learning aids in the MM versions led to a performance differential in favour of the holist subjects. VR groups predominated over MM when subjects were serialists. Among holist subjects results were more mixed.

Performance on VR versions was superior to MM groups among high users of spatial aids but not low users. Within MM, MMSPAT outperformed MMCTRL again among high users of spatial aids. Among high and low users of meta-cognitive features, the VRMETA version of the field-trip benefitted both high and low-users of meta-cognitive features equally over MM versions. These sets of results were interpreted as lending further support to the affordances and eclectic learning hypotheses respectively. Over all tests, subjects unfamiliar with Holyrood Park were better supported by VR conditions than MM ones.

9.4.2 Analysis of hypotheses

9.4.2.1 Spatial ability

Hypothesis 1: *High-spatial subjects will outperform low-spatial learners across spatial tests.* Excepting the Siccar Point evaluation (which used different visualisation technology), the results across most of the experimental research except for the last experiment supported this hypothesis.

Hypothesis 2: *VE's should support low-spatial learners more than MM environments.* This hypothesis was partially supported. In Siccar Point, low-spatial subjects outperformed high-spatials on the landmark test. On later evaluations there was a consistently smaller difference between performance of the high- and low- spatial subjects among the VR groups than MM groups. However on experiment six both low and high spatial subjects were equally supported to a greater extent than by the MM environments.

9.4.2.2 Learning style

Hypothesis 1: *Holists outperform serialists on spatial / non-spatial knowledge tests in a VE.*

This finding was not supported by the data. By contrast serialist learners outperformed holists when tested in a virtual environment.

Hypothesis 2: *Serialists outperform holists on tests of spatial/ non-spatial knowledge in an MM environment.* Results for the MM conditions were much more mixed. No clear support was found for this hypothesis.

Hypothesis 3: *Holists should do better in VR versions than MM versions and this should be the opposite for serialists.* This hypothesis was the corollary of the first two. Given that the first two hypotheses were not supported, this hypothesis was also not supported. Performance was better across the tests for the VR group against the MM groups only when the subject sample consisted exclusively of serialist learners.

9.4.2.3 Prior knowledge

Hypothesis 1: *Frequent visitors to Holyrood Park would perform better across the spatial and non-spatial tasks than infrequent users.* No clear difference was found between these groups. Instead each group performed differently with the less frequent visitors being better supported by the VR versions than the more frequent ones.

In summary, several individual differences among subjects were analysed in the research. The emergence of unplanned differences among the subjects served as a note of caution to the design of such experiments. Many extraneous variables may easily interfere with the collection of useful data. Furthermore the discovery of differences in the usage of materials in the final evaluation served as a vindication of the usefulness and importance of the process-based approach to evaluation.

9.5 Usability issues

9.5.1 Summary of research

The research began with a detailed user-needs exercise with the students and educationalists of the geology department. This analysis used interviews and questionnaires to elicit the relevant types of knowledge taught at geology field-courses. After the Siccar Point evaluation, students were again consulted for their opinions on the courseware. Qualitative data suggested they were reasonably happy with the field-course though some serious problems were highlighted. These included the lack of appropriate orientation and navigation features and the slow down-loading of images. Regarding the quality of spatial information, the ratings of dissatisfaction were higher among the control group than among the experimental subjects. This implicitly suggested that the provision of spatial information had reduced feelings of disorientation to some extent among the experimental group.

In response to this feedback many improvements were made to the interface design and the provision of spatial information. A second round of usability evaluation incorporated into experiment 2 found that the VR group were generally satisfied with the interface and the technology. Nonetheless they reported the highest levels of dissatisfaction with any limitations in the technology. This was thought to be related to increasingly high expectations as the technology became more sophisticated. Additionally, individuals suggested that the orientation features of the supplementary field-trip were not a priority. Instead familiarisation with the technology, and then the learning of the geology was most important. This was an important revelation since it suggested that subjects were misinterpreting what was expected from them in the experiment.

Given the application of usability information throughout the evaluations, significant improvements were incorporated into successive versions of the virtual and multimedia field-courses. This is perhaps one reason data relating to usability was quite positive for the final version of the field-course. This resulted in improved enjoyment ratings across all groups with the most sophisticated VR version receiving the highest rating. One major usability issue however was the differential usage of the spatial navigation and orientation aids. This problem was most marked between the VR groups and the MM groups with the latter using the features more than twice as much as their VR counterparts.

9.5.2 Analysis of hypotheses

An hypothesis running throughout the thesis was that a more usable interface and its associated technology should result in enhanced performance across most measures of learning. Additionally, ratings of satisfaction with the technology should improve as the interface becomes more usable.

Performance across the evaluation tests did generally improve across the evaluations. Though the evaluation tests are not directly comparable with each other given the modifications made to them, performance between groups and across tests became increasingly differentiated. This suggests that technology improvements enabled subjects to reach their potential. Satisfaction ratings generally increased throughout the evaluations. Furthermore, while the MM and CTRL field-courses initially received the highest satisfaction ratings, this had shifted to the most sophisticated VR versions by the final evaluation. The nature of the feedback from subjects also changed. Comments improved from outlining fundamental problems with the interface to more superficial criticisms.

9.6 Consolidation of the research

A framework for learning with virtual environments was proposed in chapter five. This consisted of three main components: desktop virtual environments, an eclectic pedagogical framework, and the incorporation of spatial information. These components were described as interdependent through the mechanisms of spatial affordance, reification of learning and the spatialisation of information. These components and mechanisms were described as interacting with each other to produce the optimal conditions for which learning through a virtual environment might occur. Additionally, all elements of this process were described as inextricably affected by individual difference factors.

Most mechanisms of the model and the components underlying them were supported by the experimental research. Most strongly supported were the affordances provided by virtual environments for spatial information, the use of eclectic learning features (and to a lesser extent), the reification of learning and the influence of individual differences. The weakest parts related to the spatialisation of information.

Spatialisation of information refers to the means by which spatial and non-spatial information may be integrated in memory. Reasons for the lack of enhancement to learning from the conjoint presentation of spatial and non spatial information in the computer-based learning environments were highlighted in chapter eight. These included the lack of proper control over the way in which spatial and non-spatial information was presented. Ensuring the presentation is closely matched between the two types of information is something that needs to be implemented in any future evaluation. This was attempted in early experiments but usability problems caused by the slow down-loading of aerial images and maps led to their optional presentation. The intention was that subjects should review the images in conjunction with the geology information at every available opportunity though clearly this did not happen even with high users of the aerial images. Since those early evaluations many improvements to the interface have been made which have lead to much speedier access to the information. The reintroduction of automatic or constant map displays could be considered in light of these modifications. Thus, close conceptual and physical proximity would appear necessary for the benefits of spatialised learning to be realised. Until such practical issues are resolved, theoretical reasons for the lack of spatialisation of the information should be set aside as explanations.

The more successful parts of the framework such as the affordances of virtual environments for spatial learning were confirmed by the research. Such advantages have been described elsewhere (e.g. Winn, 1997) as important pedagogical features of virtual environments. A similar mechanism relating to non-spatial information was the reification for learning of virtual environments. This describes the affordances of such environments to lever the visualisation and comprehension of non-spatial information. Limited support was found for this mechanism. It was thought that the main reasons were the lack of control over the way that the virtual environment presented the non-spatial information. A related feature of this part of the framework was the evaluation of the elements of the eclectic learning approach. These were incorporated as a set of pragmatic guidelines for designing virtual learning environments. Some of these features such as the embedded feedback questions and the presentation of information from different perspectives lead to enhancements in the learning process. Other features such as the emphasis of process-based evaluation produced a significant amount of fruitful data particularly for the final experiment.

The remaining elements of the framework were the focus on individual differences and usability design. Individual differences emerged as the most important feature of the framework. They included differences in cognitive ability and strategy, prior experience, fluency with the English language and the use of spatial and learning features. Particularly interesting was the consistent support that virtual environments provided to learners classed as low in spatial visualisation ability along with the finding that both high and low-spatial subjects were equally supported in the final evaluation. This confirmed earlier predictions of the potential remedial effects of virtual environments. More surprising were the benefits to learning experienced by serialist learners in virtual environments. However the most important aspect of that finding was the fact that consistent differences were found between the two subject groups throughout the conditions.

Virtual environments magnify existing learning differences among individuals. The research confirmed the necessity to accommodate individual differences as something that pervades all stages of learning in virtual environments. The desire to incorporate individual differences into the framework serves only to strengthen the validity of it as a framework for describing learning in virtual environments. It also enriches the descriptive power of the framework for different learner populations. However, this serves only to acknowledge the role of individual differences in the research. What is ultimately required and what the research here suggests is that any such framework must become more learner-centred in its whole approach. This entails making individual learning differences the focus of any approach that attempts to describe and prescribe learning. It requires a mechanism for anticipating and accommodating those differences among learners by structuring the learning environment to support them. This does not imply a return to a constructivist approach. If anything it is the opposite of constructivism in that it advocates a tightly structured but flexible learning environment that is designed to respond to and support individual cognitive differences in learning. This brings together the eclectic approach of chapter 2 and the framework for virtual environments in chapter 5 by suggesting that these approaches to learning offer the best possible context for meeting the requirements of a learner-centred pedagogy. The key element of this is the role of virtual environments since they offer both the power and the flexibility to become more responsive to the needs of the learner.

Learning in virtual environments (or indeed any other computer-based framework) is ultimately subject to the usability of that environment. The research in this thesis clearly demonstrates the importance that needs to be attributed to careful usability design. It also emphases the need to engage in a process of formative usability evaluation. This ensures that the usability is constantly improved in response to user feedback and indirect evaluations. Precisely this process was followed within the current research. As a result both the usability and the validity of the pedagogical evaluations improved throughout of the experiments. This further strengthened the validity of the framework as a basis for learning with desktop virtual environments.

9.7 Chapter summary

This chapter synthesises research findings with the hypotheses from the framework for learning with VR. Most of the hypotheses are supported, the main exception being the spatialisation of information. Nonetheless, these findings provide a comprehensive description of learning with desktop virtual environments. However they are merely a tentative first step; a basis for exploring ways of learning with this technology.

VR magnifies individual differences among learners. While the framework as an integrated prescription for learning with VE's did not meet all of its expectations, it nonetheless demonstrated the complexity of that learning by accommodating the role of individual differences. These differences, which are latent in most learning situations, are exposed and magnified by virtual environments. And, as seen in the research reported for this thesis, these differences can come to dominate the learning that occurs. This finding necessitates the acknowledgement of a learner-centred pedagogy for virtual environments.

10.

Conclusions

This thesis set out to test the hypothesis that desktop virtual learning environments are effective tools for learning. To this end it was largely successful. Most components and mechanisms of the framework for learning with desktop virtual environments were supported though the level of such support varied from slight trends to significant differences. Beyond this, the research included a program of extensive usability evaluation, the results of which were incorporated into the design of the virtual environment for further evaluation. In this final chapter, the main contributions of the thesis are summarised. This is followed by a brief consideration of the quality of the data that coincides with a discussion of some limitations of the research. Finally, some avenues for future research are presented.

10.1 Summary of research

This thesis set itself two main objectives. The first was to describe the mechanisms and processes of learning using a desktop virtual environment. The second was to modify and evaluate the usability of that environment to contribute to a more effective learning experience. These objectives corresponded to two levels of description in the thesis: theoretical and practical respectively. Regarding the theoretical perspective, the first step was to review the literature in instructional design, spatial cognition and virtual environments. Chapter two reviewed the literature on instructional design. Two main perspectives on learning: the information processing / cognitivist perspective and the constructivist perspective were described and their assumptions analysed. The cognitivist perspective emphasised the importance of goal-directed, componential and transferable learning. The constructivist approach placed most emphasis on the active construction of knowledge, social interaction, contextualised learning and meta-cognitive awareness. Each of these perspectives was found to suffer from several criticisms mostly based on prescriptions related to their philosophical approach to knowledge. For information processing these included a lack of environmental complexity, a poor appreciation for individual differences, and a lack of recognition for the relevance of social variables in learning. Constructivist criticisms included a lack of structure in learning, failure to recognise decomposition and transfer of some knowledge, and an overemphasis on complex and authentic learning situations.

To resolve these differences and to develop a relevant theory of instructional design for virtual environments, an eclectic perspective on learning was proposed. This view adopted successful aspects of the two perspectives and merged them into a view of the learner as one who intelligently adapts to his or her environment. However the learner is someone that also needs to be guided in a structured but flexible environment. This approach emphasised: knowledge may be actively constructed, real world complexity, prior knowledge, goal-structured but flexible learning environments, social factors, and individual differences among learners. The approach also emphasised the importance of process-oriented evaluation and meta-cognitive awareness of the learning situation. Some of these elements of the eclectic approach were adopted in the design of the virtual learning environments and were evaluated for their effectiveness.

While an appropriate instructional design framework is important, the spatial element of a virtual environment is also relevant. Chapter three described how an understanding of spatial cognition in both real and virtual environments might contribute to a description of learning from a desktop VE. This chapter illustrated the conventional views on the structure and acquisition of spatial knowledge. It presented examples of studies showing how the spatial knowledge acquired from virtual environments is similar but not identical to that acquired from real environments. Areas of difference included the acquisition of survey knowledge and the many distortions that users are liable to when acquiring VR-based spatial information. It was briefly mentioned how virtual environments may contain affordances in the Gibsonian sense, to enhance the integration and acquisition of spatial information. The discussion then extended to a survey of existing spatial navigation aids in real and virtual environments. These were considered important since they are the principal means by which spatial orientation and navigation may be enhanced in virtual environments. Thus, combining spatial navigation aids with the affordance of virtual environments for spatial information might be expected to lead to more enhanced learning from such environments.

The remainder of the chapter examined research describing how the integration of spatial and non-spatial information in memory may lead to enhanced memory and learning of that information. Two main approaches were examined: the conjoint retention hypothesis, which is based on a dual-coding view of memory, and the idea of spatialised propositions from research on semantic priming. The chapter ended with a discussion of the role of individual differences in the research.

Chapter four brought the other two reviews together by discussing the nature and relevance of virtual environments for learning. It began by describing a functional decomposition of the technology ranging from non-immersive desktop to fully-immersive VR. This discussion narrowed to a description of the technology used for developing virtual environments in the thesis. The affordances of virtual environments were again discussed in relation to how these environments may enhance learning and provide a more effective medium through which learning may occur. The effective pedagogical features of virtual environments included the opportunities for exploration (both spatially and semantically), performance assessment, sense of scale, simulation, repeatability and abstract representation. This discussion also emphasised the ability for knowledge to transfer from virtual to real environments. These educational features were also related to a discussion of the importance of immersion and interaction with the VR technology used in the thesis. The main point from this was the idea that as the levels of immersion conveyed by a VE decrease, the relative importance of interaction increases proportionately. The chapter concluded with a review of how the eclectic principles regarding evaluation and assessment may be integrated into a desktop virtual environment.

Together these three chapters laid the foundations for the research described in the rest of the thesis. In chapter five the main themes from the literature reviews were extracted and described in more detail. These themes consisted of:

- Affordance of spatial knowledge acquisition by virtual environment
- Eclectic framework for learning and evaluation
- Spatialisation of information
- Role of individual differences
- Usability issues with virtual reality research

From these themes a framework was proposed describing how such themes might come together and interact to produce an idealised view of learning within a desktop virtual environment. The framework consisted of three components: desktop virtual environments, the principles of the eclectic learning approach and spatial information, with three mechanisms of interdependence: reification of learning, spatial affordances and spatialisation of information. Surrounding all these elements of the framework was the role of individual differences. These differences arose from cognitive, motivational and experiential factors and were regarded as an essential element of the learning process. Together these components and mechanisms were presented as an idealised framework for acquiring knowledge in a desktop virtual environment. Part of the focus for the experiments described in chapters six through eight was to find support for the predictions of the framework.

Support for the hypotheses based on the framework were described in chapter nine. Most elements were supported to some extent. The most strongly supported features related to the affordances of virtual environments, the effectiveness of the eclectic learning model and the role of individual differences. Less impressive was the mechanism of spatialising information.

10.2 Contributions

10.2.1 A basis for learning with desktop virtual environments

A major contribution of this thesis was the description and evaluation of a basis for learning with image-based desktop virtual environments. Beginning with a critical analysis of the instructional design literature, the thesis synthesised the most relevant ideas and filtered them through a pragmatic approach to learning and evaluation. Following a review of the research literature it further extended this approach to apply to learning in the context of desktop virtual environments. Several components of learning with this technology were proposed and then evaluated in authentic learning environments through six experiments. All of these components were supported to some extent throughout the research for specific groups of individuals. Most successful were the elements of the eclectic framework, the affordances of spatial information and more indirectly the spatialisation of information and the reification of learning. The thesis demonstrated these components to be important elements of the learning process that when adopted in virtual environments acquire additional value and effectiveness. Furthermore, they were shown to represent a viable description of the learning process with desktop VE's. Individual differences were also acknowledged as an integral part of the learning process. The influence of individual differences in the research necessitated a reconsideration of how a prescriptive pedagogy could best accommodate such differences. A realignment of the framework for learning around the individual cognitive needs of the learner was suggested. This presented an altogether different approach to how one views the role of the individual in the learning process.

10.2.2 Individual differences

Apart from acknowledging their integral role in the framework for learning, the thesis highlighted the relevance of individual differences (ID) to any discussion of learning. First it expanded the definition of ID to include:

- differences based on cognitive abilities (spatial ability and learning style)
- learning strategies
- experiential differences and prior knowledge
- interface / motivation / other differences

Cognitive ability differences included the differences in spatial ability and learning style. These were planned differences among groups. Differences in learning strategy referred to the alternate strategies adopted by subjects when learning and completing the evaluation tests. For example, there was considerable evidence that many subjects used a pattern-matching strategy rather than a spatial one on the transformation spatial tests in experiment two. Differences based on prior experience, knowledge of the environments or the content of the field-courses also interacted with the information presented. The most interesting of these was the finding in experiment six that subjects who had been to Holyrood Park less often performed better in some spatial evaluation tests. Finally, there were several examples of differences between individuals based on motivation, usage of the interface features and linguistic differences. The discovery and investigation of this range of differences contribute to a broader definition of the role of ID in learning. It also highlights the prevalence of such differences at all levels of the learning process and in doing so contributes to a greater understanding of their role.

This recognition of ID's importance to any learning situation may also be used to add another perspective to the way information is analysed. Throughout most of the experiments (especially chapter 8) analysis of ID data provided an important perspective on the effectiveness of learning environments for various groups of individuals. This was further illustrated by the process-oriented approach to evaluation that was wholly adopted for experiment six. Its effectiveness as an evaluation tool served to further strengthen the eclectic framework for learning.

Perhaps the most important contribution of the ID research was to show how desktop VR technology may support certain learning styles and abilities more than others. If it could be shown that this technology had a remedial effect for certain individuals then the implications for educational application are significant. Consistently though modestly throughout the studies, virtual environments supported those learners classified as low on spatially ability. While the final evaluation showed support for both high and low spatial subjects in VR, this was also far better than performance among those groups in the MM field trip. Other unexpected trends included the performance of serialists on VR. These findings emphasise again the rich interactions that occur between the individual and the technology along so many axes of ID's.

10.2.3 Desktop VE's as tools for learning

The thesis also established the clear value of desktop virtual environments as learning tools in their own right. There are many advantages for using such technology over other forms of computer-based or virtual learning environment. First, as the research in this thesis broadly showed, such environments are effective for acquiring knowledge in a given discipline. Clearly they may be more suited to the teaching of certain types of information than others. For representing the essential elements of a geological field-trip they are quite successful. Indeed the VLDTK project extended the applicability of desktop virtual environments to two other content domains: veterinary science and meteorology. In the first case desktop virtual environments were employed to present information on canine abdominal anatomy using VRML-based models of organs. For meteorology, satellite data sets were presented and manipulated in three dimensions to enable students to classify relevant features. These two examples illustrate the way that desktop virtual environments may be effectively employed as teaching and learning tools in other domains.

Desktop VE's are also cheaper to buy, develop and maintain than more immersive systems. This is an important issue since it is the cost-effectiveness and educational efficacy of the technology that determines whether it is adopted more widely in schools and universities. Desktop virtual environments are by their very definition, environments that run on desktop computer systems including Windows-based PC's and Apples. Usually the only interaction tools required are the standard mouse and keyboard. This increases their attractiveness to educational content providers since they can deliver high quality virtual environments at minimal cost to themselves or their institutions. With the phenomena of distance-learning and virtual universities now becoming a reality, the ability to provide such unique learning experiences across the Internet becomes extremely important. In this respect the thesis has served to highlight further the advantages and unique value of desktop virtual environments.

10.2.4 Usability

Apart from supporting the framework for learning with desktop VR, the experiments of the thesis also served another purpose: improving the usability of the virtual environment. This was achieved by incorporating a program of usability evaluation and design into the development of the virtual environments. This program consisted of:

- a content-providers' consultation exercise
- user-needs analysis (questionnaire, interview and observation techniques)
- formative evaluation (cognitive walk-through's of the virtual environment)
- summative evaluation

The usability cycle began with the design, construction, application and evaluation of the virtual environments. The outcome of the evaluation fed back into proposals for improving the usability of the interface and technology generally. From these, a modified virtual environment was developed and further evaluated and thus the cycle began again. This cycle of developing, evaluating and modifying the technology played a key role in improving the learning that occurred with the VE. In many ways this was perhaps the most significant contribution of usability to the thesis. It achieved this by influencing the evolution of the VE towards being a learning environment that more closely served the needs of the users. This is evident from the earliest investigations into user-needs analysis in chapter 6, right through to the final evaluation. Indeed the discussion sections for each experiment documented the conclusions of the evaluations and the steps necessary for acting on those conclusions in the following evaluation. Recommendations for modifications were carried out wherever possible.

Incorporating usability evaluation into the research also showed the extent to which the Internet and virtual environments are suited to supporting usability and other forms of evaluation. With these technologies much of the usability evaluation may occur online in real-time as the user is interacting with the technology. This was demonstrated with the power of the process-oriented approach. Such technologies make the process of presenting and processing the output of usability evaluation more efficient and less labour intensive.

Most interesting however was the effect that usability evaluation had on the tools and methodologies of evaluation. Not only did such evaluation lead to the modification of the interface and the technology, but it also had the adaptive effect of leading to the refinement of the very tools that were doing the evaluation. In this sense the usability component may be regarded as a self-organising element that was constantly attempting to reach the 'steady-state' of complete user satisfaction with the technology. Achieving greater levels of equilibrium between the user and the technology had the effect of making the methods more valid and reliable over the course of the research.

10.3 Limitations

10.3.1 Bandwidth

One stipulation of the original VLDTK project was that the virtual environments should be deliverable across the Internet. This was reasonable given their application in higher education and the desire to make them as widely available as possible. Though potential bandwidth problems were foreseen, it was expected that the Internet would have become a much faster and efficient network by the end of the project. Unfortunately this was not so. While the web has certainly become faster, it is still not capable of delivering anything other than a web page with moderate to low graphics requirements.

This imposed a severe constraint on the development of the virtual environments. In preparation for the Siccar Point evaluation and in response to user input, a wide selection of multimedia was developed for inclusion in the virtual environment. These included fly-through movies, VRML replicas of Holyrood Park, virtual tutors, animated images, a large selection of audio clips and high resolution images of maps and interactive aerial images. Most of these features could not be used in later virtual environments due to the data-intensive nature of their content. This precluded the use of much multimedia content that could have had a significant impact on the learning that occurred.

One could argue that the Internet constraint did not apply to the Ph.D research and thus such environments could have been played on the hard disc of a PC. There are two arguments against this. First, all the programs for recording and processing the data logs and evaluation information were using scripts that were web-based and were delivered from a different machine. This was necessary since for some evaluations there were up to 40 subjects using the computers simultaneously. Secondly, the reason the VLDTK project insisted on delivery across the Internet was due to the increasing importance of distance-learning using that medium. The research carried out for the thesis was similarly concerned with developing a framework for learning that could be applied to actual learning situations. It was thus felt that the environments should be developed and research carried out under circumstances that were as authentic as possible.

However, it would appear that the technology is finally beginning to catch up with Internet-based virtual environments. Several new technologies for delivering broadband information across the Internet are currently being developed and are in the process of being made available. These include ADSL (asymmetric digital subscriber line), cable and satellite technologies all of which promise to deliver data at speeds of up to 2Mbps (megabytes per second) instead of the current 56Kbps. Certainly at these speeds, the delivery of more impressive and faster loading virtual environments seems a possibility.

10.3.2 Software

While Reality Studio was generally usable and flexible it was also problematic in that it imposed several constraints for the development of virtual environments. One such problem was with the development of animated images. Use of animated images can help describe temporal processes such as erosion and deposition. However, there is a problem with using animated images in RS. Despite the frame rate that may have been set when the image was created, RS plays it as fast as it can go. This may be suitable for some applications where a smooth fast transition from frame to frame is required. However, with more complex animations they can be problematic. One way of overcoming this problem is by making the animation manual, rather than automatic. Thus with a manual animated image, when one wishes to change frames they click on the image and the transition occurs. This is easily achieved by layering several images and linking them in the appropriate order. The only disadvantage with this method of animating images is that the user is limited to the number of layers available in RS which is eight.

Another problem with the software emerged when the virtual environment being created grew to a certain size. At one point the virtual environment contained over 36 megabytes of information. At this point the software completely crashed and it was not possible to proceed any further with development. It was only when the size of the environment was reduced through the removal of a panorama and its associated multimedia elements that the software became usable.

Other 'bugs' included the fact that it was not possible to set the virtual environment to communicate with information in the web page within which it was embedded. An example where this was necessary was with the Holyrood Park environments. There, information in the virtual environment was contained in a viewer window embedded in the top frame of a web page. In the bottom part of the web page information relating to the contents of the viewer was presented. If the user navigated to a new location in the virtual environment, the information in the bottom frame would not be updated. Thus, the information in the two halves of the web page would be out of synchrony. Overcoming this problem required hacking the programming code for the virtual environment.

10.3.3 Subject matter

Another issue related to the nature of the subject matter and the types of subjects used. Geology was the chosen domain for applying virtual environment technology in the VLDTK project. Since the virtual environments were constructed to present a geology field-course it was not possible to change the subject matter in later evaluations. This was not a problem for early evaluations where geology students were used as subjects. However in later studies after the VLDTK project had ended, it was only possible to use non-geology students to gain sufficient numbers for participation. Since the content was aimed at first year undergraduate geology students it meant that the standard of difficulty of the material was not too high. However since the participants were not geology students, many found the content to be rather boring and uninteresting. As a result some subjects reported that they found it difficult to motivate themselves to concentrate on the geological material.

10.3.4 Field research

Some of the experimental research was field-based, particularly experiment two. This introduced its own set of challenges for evaluating the outcome of learning under those circumstances. For example, subjects explored Holyrood Park in small groups, each of which was accompanied by a demonstrator. As with the field-trips organised by the geology department, there was no control over the manner in which a demonstrator conveyed the geological information of the park. Despite being given guidelines on what features to explore with the subjects, qualitative feedback later revealed that the styles of teaching between the demonstrators were quite different. While the content may have been the same, the emphasis was placed on different aspects of that content.

10.4 Future directions

Many suggestions were made in previous chapters of ways to further improve the research. In this section more general issues are considered for developing this research further.

10.4.1 Test of spatialisation

While much of the weakness of the spatialisation element of the model may have been due to poor correspondence between spatial and non-spatial information, there may also have been a theoretical element. A theoretical reason for the weak performance is the possibility that the inclusion of aerial images may have interfered with the production of spatial representations for the virtual environment. This may have been likely if the structure of those representations were scene-like spatialised images, which would correspond with a conjoint retention interpretation of spatialisation. This could be evaluated by including an additional condition that includes all of the spatial features included in the present evaluation, but omitted the aerial images. This might ensure that spatial representations produced from the virtual environments did not conflict with those produced by the aerial image and therefore result in poorer performance across spatial tests.

10.4.2 Adaptive virtual environments

A major aspect of this research has been to highlight the significance of individual differences in learning, particularly the extent to which the learning environment interacts with such differences. The need for a learner-centred pedagogy to fully address the role of such differences was emphasised in the last chapter. A key aspect of that is the development of learning environments that are designed around the individual differences of the learner. One possible avenue for future research would be to pursue ways of developing learning environments that are more responsive to the learner. These adaptive environments may result in greater effectiveness for teaching and learning if they can respond to users' individual cognitive differences. One attempt at such a proposal using multimedia environments was reported by Hynes and Valley (1995). They developed multimedia courseware aimed at teaching about image-processing. Four different versions of the courseware were developed based on four profiles of users' learning styles. These profiles were:

- theorist - prefers wider underlying theory to be discussed in more detail
- pragmatist - prefers putting theory into practice
- activist - prefers 'doing' first followed by theory later
- reflector - prefers to observe first followed later by an opportunity to 'do'

The idea of designing learning environments that can be responsive to the individual differences of a learner is a necessary one given the differences in outcome reported for different types of subjects.

10.4.3 Edutainment

A limitation of the present research was the nature of the subject matter and the fit of the subjects to the content material. Clearly subjects are going to be more motivated if they are interested in the content. One way of addressing this is to use the technology to make learning more fun and stimulating. Dede (1994) has written of the value of introducing game-like elements into learning environments to provide enhanced motivation. Similarly Psotka uses the word edutainment to describe this convergence of education and entertainment. He hails the emergence of such a phenomenon as one that will have "enormous potential consequences for education" (Psotka, 1995). Clearly with the incredible appetite for video games, people are becoming more sophisticated in their expectations of what computer environments are capable of. Similarly, designers might consider using some features from such games to create more interesting and engaging virtual learning environments. Introducing traditional game-like elements such as role-playing and 'magic' features could go some way towards satisfying this need.

10.5 Final words

This thesis has made a unique contribution by describing a basis for learning with desktop virtual environments. It has done so in two ways. Through a reanalysis of the instructional design literature and a synthesis of research on spatial cognition and virtual environments, a theoretical framework for learning with such technology was proposed. Through empirical analysis many components of the model were supported. Individual differences were highlighted as a significant factor in learning with virtual environments. However, the thesis also described the evolution of a virtual environment and the relevance of usability evaluation for developing more effective learning technologies. The arrival of the Internet poses many new questions and challenges old dogma. The implications for education are enormous. This thesis is a first step towards a new way of thinking about learning with technology.

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Appendices

Appendices 235

APPENDICES A - E: EXPERIMENT DATA

APPENDIX A - DATA FROM BARN'S NESS QUESTIONNAIRE

FINDINGS FROM QUESTIONNAIRE DISTRIBUTED TO STUDENTS ON THE BARNS NESS FIELDTRIP

1 Returned questionnaires

OVERALL= 102	MALE= 60	FEMALE= 42

2 Content

2.1 Was it obvious what the objectives of today's fieldtrip were?

OVERALL	MALE	FEMALE
Yes= 88 (86.3%)	Yes= 49 (81.7%)	Yes= 39 (92.9%)
No= 12 (11.8%)	No= 9 (15%)	No= 3 (7.1%)
DK= 2 (2%)	DK= 2 (3.3%)	DK= 0 (0%)

DK (Don't Know

Table A-1: Ratings of how obvious objectives were.

2.2 Rate the accuracy of the educational information generally provided on the fieldtrip by tutors, lecturers, other staff, fellow students and supplementary material

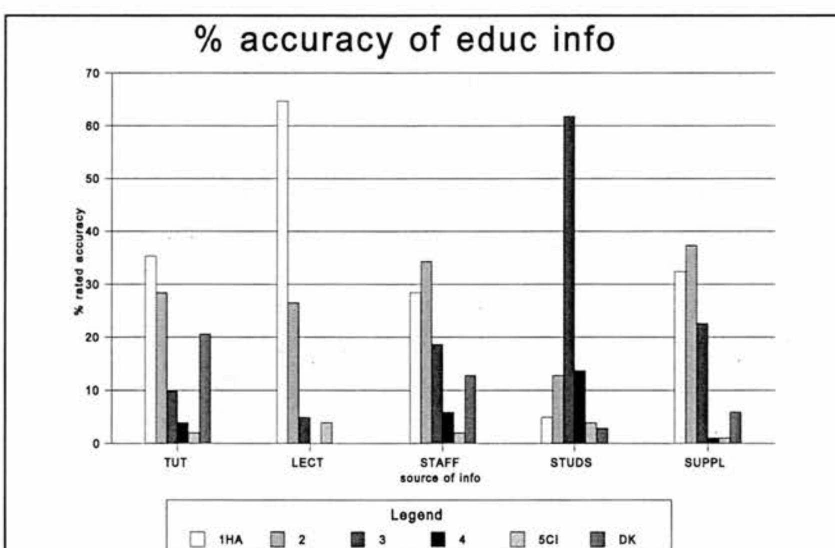


Figure A-1: Rated accuracy of education information

How would you improve the accuracy of the educational information that you receive?

- more detailed information
- brief staff members before trip to ensure consistency of information among staff
- state general aims and objective more clearly and accurately

2.3 Is the supplementary material (eg notes, lectures, tutorials etc.) provided as background information on a fieldtrip sufficient for your needs? What additional information would you like to see provided?

OVERALL	MALE	FEMALE
Yes= 79 (77.5%)	Yes= 49 (81.7%)	Yes= 30 (71.4%)
No=18 (17.7%)	No= 9 (15%)	No=9 (21.4%)
DK= 5 (4.9%)	DK= 2 (3.3%)	DK= 3 (7.1%)

Table A-2: Adequacy of supplementary information.

2.4 What is the role of your demonstrator on the fieldtrip? How would you extend this for your benefit?

Answers clustered around:

- providing help and advice to students
- describing and pointing out important features of the site
- answering questions and promoting discussion
- helping to structure the students ideas
- and maintaining enthusiasm and interest among the group

3 Learning

3.1 Do you receive feedback on your work from a field excursion?

OVERALL	MALE	FEMALE
Never=14 (13.7%)	Never= 8 (13.3%)	Never= 6 (14.3%)
Seldom=19 (18.6%)	Seldom=14 (23.3%)	Seldom= 5 (11.9%)
Sometimes= 31 (30.4%)	Sometimes= 17(28.3%)	Sometimes=14 (33.3%)
Frequently=18 (17.7%)	Frequently= 8 (13.3%)	Frequently= 10 (23.8%)
All the time=18(17.7%)	All the time= 11 (18.33%)	All the time= 7 (16.7%)
DK= 2 (2%)	DK= 2 (3.3%)	DK= 0 (0%)

Table A-3: Feedback received.

Sources for this feedback included:

- exam results
- assessment results
- other field-trips where previous trips are used as a reference
- questionnaire marks
- Internet
- lectures
- practical demonstrations

- lecturers
- demonstrator

What kind of influence (if any) does this feedback have on the quality of your fieldwork?

OVERALL	MALE	FEMALE
no influence= 34 (33.3%)	no influence= 18 (30%)	no influence= 16 (38.1%
negative influence= 2 (2%)	negative influence= 2 (3.3%)	negative influence= 0 (0%)
positive influence= 54 (52.9%	positive influence= 29 (48.3%)	positive influence= 25 (59.5%)
DK=12 (11.8%)	DK= 11(18.3%)	DK= 1 (2.4%)

Table A-4: Influence of feedback on field-work.

3.2 Do you regard the collaborative aspects of a field trip as useful for learning?

OVERALL	MALE	FEMALE
Yes= 96 (94.1%)	Yes= 55 (91.7%)	Yes= 41 (97.6%)
No= 3 (2.9%)	No= 3 (5%)	No= 0 (0%)
DK= 3 (2.9%)	DK= 2 (3.3%)	DK= 1 (2.4%)

Table A-5: Usefulness of collaboration.

3.4 How effective is fieldwork for teaching about the structures of a landscape? Could this be improved?

OVERALL	MALE	FEMALE
Yes= 34 (33.3%)	Yes=21 (35%)	Yes= 13 (31%)
No= 55 (53.9%)	No= 32 (53.3%)	No= 23 (54.8%)
DK=13 (12.8%)	DK=7 (11.7%)	DK= 6 (14.3%)

Table A-6: Potential for improvement in teaching about geological features.

4 Attitude to technology

4.1 For how many hours per week (approx.) do you browse the Internet and/or send and receive email?

OVERALL	MALE	FEMALE
NONE= 4 (3.9%)	NONE= 3 (5%)	NONE= 1 (2.4%)
0.5= 7 (6.9%)	0.5= 5 (8.3%)	0.5= 2 (4.8%)
1= 17 (16.7%)	1= 12 (20%)	1= 5 (11.9%)
2= 29 (28.4%)	2= 16 (26.7%)	2= 13 (31%)
3= 9 (8.8%)	3= 6 (10%	3= 3 (7.1%)
4= 11 (10.8%)	4= 4 (6.7%)	4= 7 (16.7%)
5+= 18 (17.7%)	5+= 7 (11.7%)	5+= 11 (26.2%)
DK= 7 (6.9%)	DK= 7 (11.7%)	DK= 0 (0%)

Table A-7: Time spent using the Internet.

4.2 Please circle those technologies you have used either for educational or entertainment purposes: World Wide Web, multimedia (eg cdrom titles, drawing packages etc.), virtual reality*, other computer technologies (please specify)?

OVERALL	MALE	FEMALE
WWW= 82 (80.4%)	WWW= 47 (78.3%)	WWW= 35 (83.3%)
MM = 52 (51%)	MM = 29 (48.30%)	MM = 23 (54.7%)
VR*= 17 (16.7%)	VR*= 10 (16.7%)	VR*= 7 (16.7)
OTHER 7	OTHER (PROG=2 WP=5)	OTHER=0
NONE=11	NONE=11	NONE=0

*Virtual reality in this context refers to any computer generated three-dimensional world, simulations of the real world, or abstract imaginary worlds that a user interacts with and participates in when using a virtual reality system.

Table A-8: Use of technology in education.

A small proportion of the students also had experience with using other computer technology. This was more comprehensive among males than females and included:

- computer programming packages
- word processing
- geology and geophysics computer programs
- dtp packages
- database
- spreadsheets

4.3 **Rate the following technologies for their relevance to geoscience field excursions: World Wide Web, Newsgroups,**

Multimedia (eg cdrom titles, drawing packages etc.), Virtual reality, Other computer technologies (please specify)

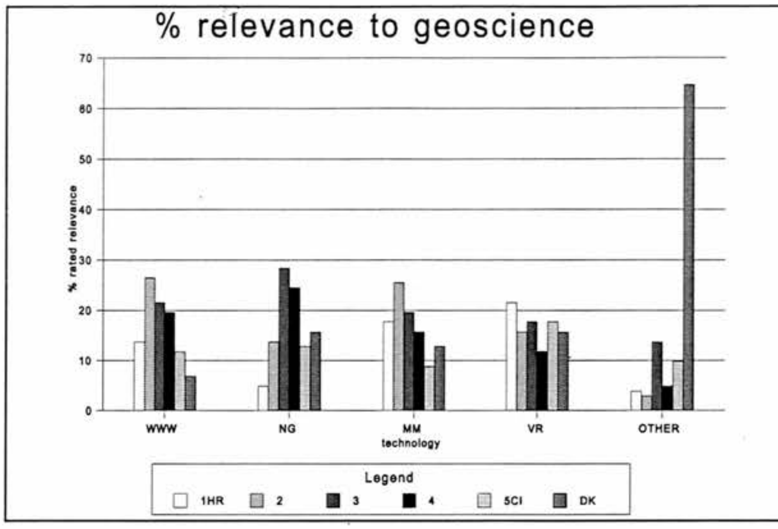


Figure A-2: Potential relevance of technologies to learning geoscience.

4.4 Would you be willing to have computer technology (of the sort mentioned in Q4.3) supplement some elements of the field excursion? Can you identify any areas of the fieldtrip which would benefit in this way? (Please state the type of technology involved)

OVERALL	MALE	FEMALE
Yes= 68 (66.7%)	Yes= 43 (71.7%)	Yes= 25 (59.5%)
No= 30 (29.4%)	No= 16 (26.7%)	No= 14 (33.3%)
DK= 4 (3.9%)	DK= 1(1.7%)	DK= 3 (7.1%)

Table A-9: Willingness to allow technology to supplement the field-course.

4.5 If your department offered students a choice between:

a) an ordinary field excursion (like the one today) or b) a computerised version of the fieldtrip containing all of the same educational information, which version would you choose?

OVERALL	MALE	FEMALE
A=82 (80.4%)	A= 44 (73.3%)	A= 38 (90.5%)
B= 11 (10.8%)	B= 7 (11.7%)	B= 4 (9.5%)
A+B= 5 (4.9%)	A+B= 5 (8.3%)	A+B= 0 (0%)
DK= 4 (3.9%)	DK= 4 (6.7%)	DK= 0 (0%)

Table A-10: Preference for type of field-trip.

5 Suggestions for improvement

5.1 In your opinion how can the field excursion be improved?

a) Without the use of computer technology?

b) With the use of computer technology?

- a reference list
- more information sheets and follow up notes
- get more organised before hand so less standing around doing nothing
- intro lecture prior to field trips
- give background theory revision on the day
- more detail on handouts
- more handouts of the area explaining features, names of places, even photographs so as to aid memory of which bit is called what and so on
- include sheets with pictures of particular examples (eg of fossils)

APPENDIX B

EXPERIMENT 1 DATA: SICCAR POINT EVALUATION

1 Revised Minnesota Paper Form Board test (RMPFB)

GROUPS	CASES	MEAN	SD
Males	75	19.448	3.919
Females	62	18.265	3.930

Table B-1: Means and SD's of the RMPFB scores for GENDER

T-test for independent samples showed no significance difference between males and females' performance on the RMPFB: $t(135)= -1.76$, $p=0.081$, ns.

2 Orientation task 1: Landmark knowledge

GROUPS	CASES	MEANS	SD
OVERALL			
SAT	75	7.973	3.526
SUN	54	4.370	3.073
PEASE BAY			
SAT	75	4.880	2.541
SUN	54	2.352	2.001
COVE HARBOUR			
SAT	75	3.093	1.337
SUN	54	2.019	1.608

Table B-2: Means and SD's of student scores on the landmark knowledge .test

Significant difference between the Saturday & Sunday groups for performance on the task of landmark knowledge: $t(122.35)=6.17$, $p<0.000$

3 Orientation task 2: Route knowledge

GROUPS	CASES	MEANS	SD
SAT	74	2.392	.718
SUN	51	2.353	.796

Table B-3: Means and SD's of the students scores in the route knowledge task

There was no significant difference between the performance of the Saturday and Sunday group on the orientation 2 task of route knowledge: t(123)=0.29, p=0.776, ns.

.4 Orientation task 3: Survey knowledge

GROUPS	CASES	MEANS	SD
SAT	71	2.789	1.715
SUN	49	2.796	1.274

Table B-4: Means and standard deviations of student performance in the survey knowledge task

A two-tailed t-test for independent samples and corrected for unequal variances was applied to the data and found no significant difference in performance between the Saturday and Sunday groups: t(117.31)= -0.03, p=0.979, ns.

5 Post VE questionnaire

LEARNING EXPERIENCE

5.1 Did you enjoy participating in the VE?

yes definitely 5 4 3 2 1 no, definitely not

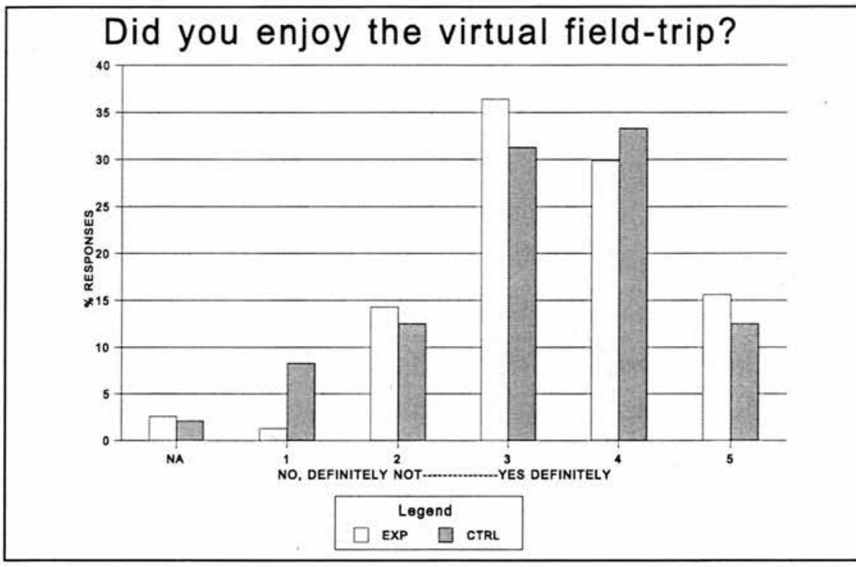


Figure B-1: Ratings of enjoyment

5.2 Did you learn something about geology by using this VE?

yes definitely 5 4 3 2 1 no, definitely not

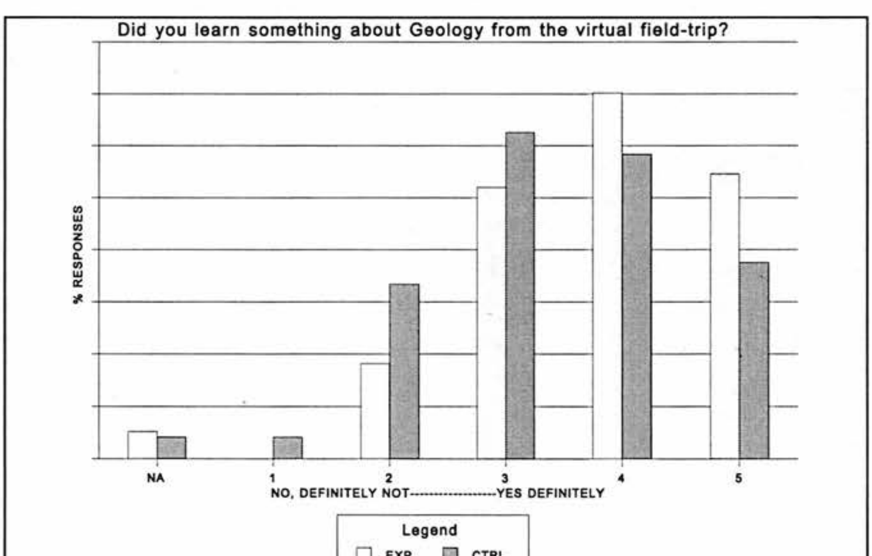


Figure B-2: Information learned

5.2.1 What do you think you were meant to learn from this VE?

- background knowledge and history
- the basic geology of the area
- spatial awareness and orientation for the real fieldtrip
- preparation to save time on actual trip in terms of having almost everything explained
- knowledge of important or significant features of the site
- association of classroom learning with real world
- summary of what has been covered in the course to date - a revision tutorial
- to learn about field sketching
- the structure of the real fieldtrip in terms of the format it will take

5.2.2 Did you?

YES / NO / NOT ENOUGH OF IT

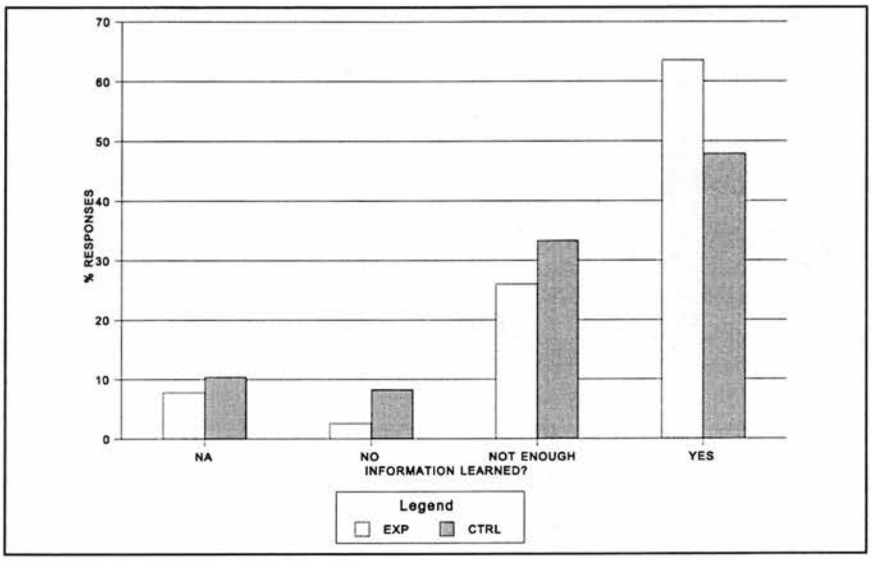


Figure B-3: Awareness of learning objectives

5.3 Do you feel the work you did in this VE complimented what you covered in lectures / other course material?

yes definitely 5 4 3 2 1 no, definitely not

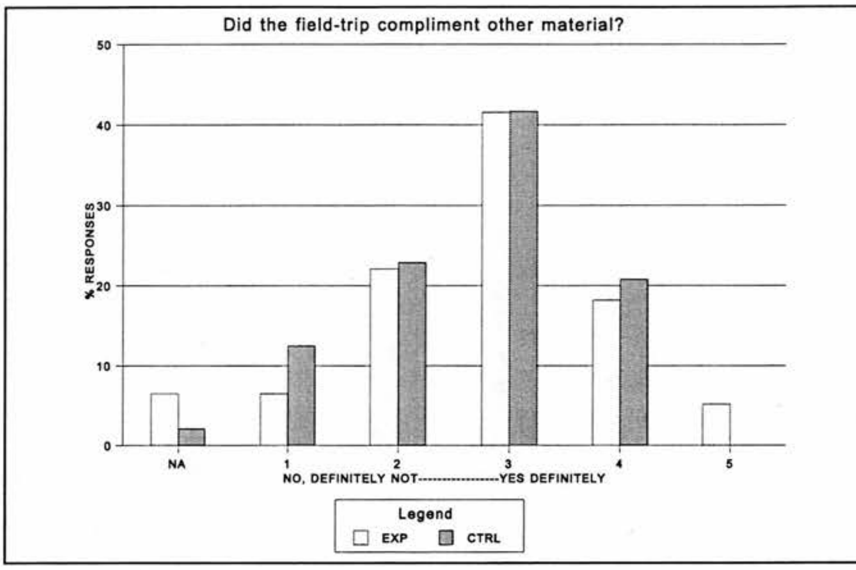


Figure B-4: Integration of field-trip with other course material

Saturday group only

5.4. Did the plate animation help increase your understanding of plate setting?

yes definitely 5 4 3 2 1 no, definitely not

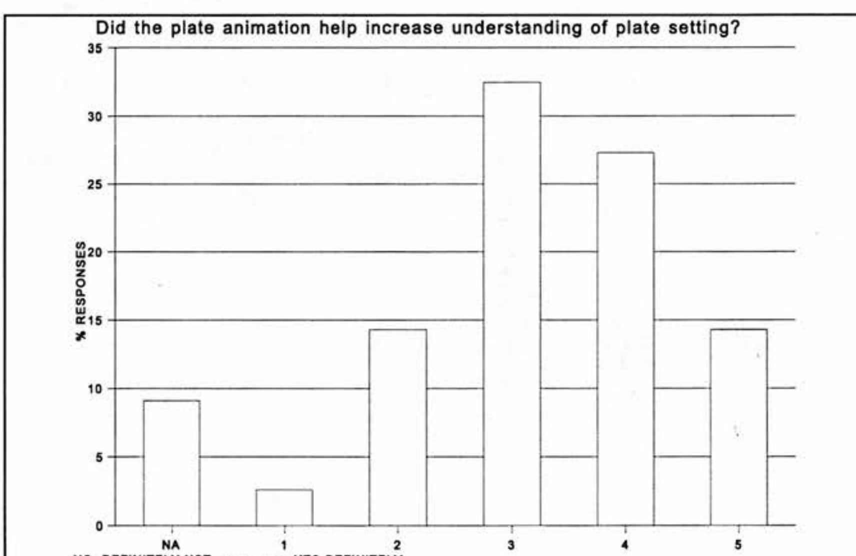


Figure B-5: Effectiveness of plate animation.

Saturday group only

5.5 Was the sketching exercise a valuable component of the VE?

yes definitely 5 4 3 2 1 no, definitely not

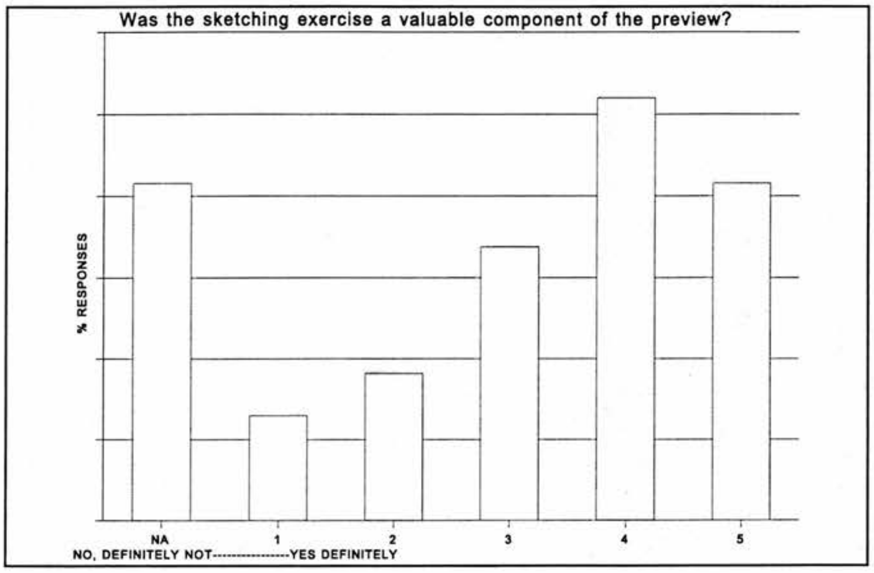


Figure B-6: Effectiveness of sketching exercise.

USABILITY EXPERIENCE

5.6 Were you ever frustrated because of limitations in how the VE functioned/worked?

yes, very often 5 4 3 2 1 no, never

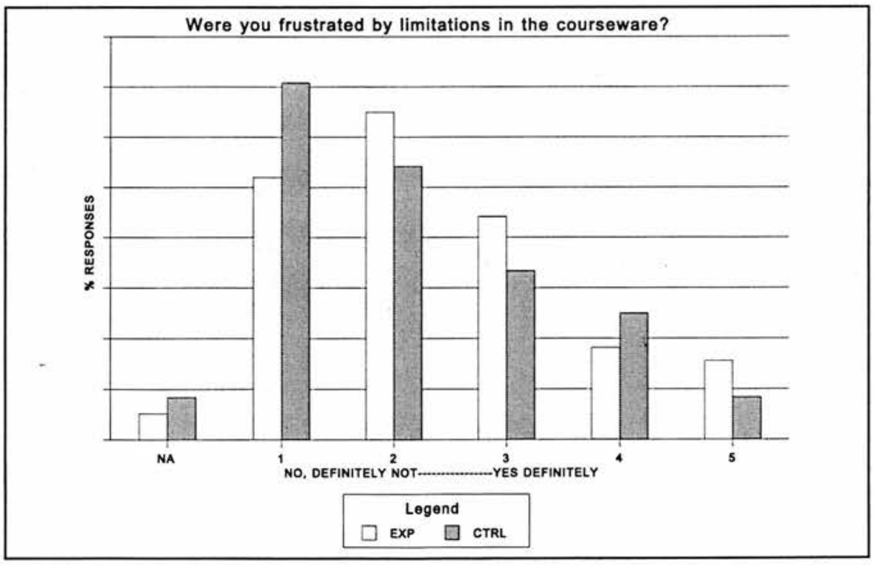


Figure B-7: Frustration at limitations

5.7 How easy or difficult was it to follow the information presented?

very easy 5 4 3 2 1 very difficult

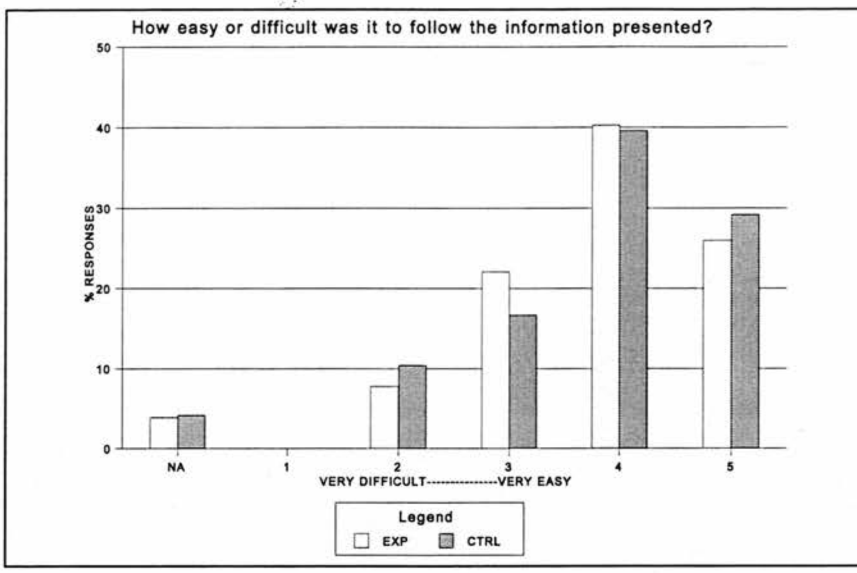


Figure B-8: Ease with following information.

5.8 How satisfied were you with the quality of the information provided?

very satisfied 5 4 3 2 1 very unsatisfied

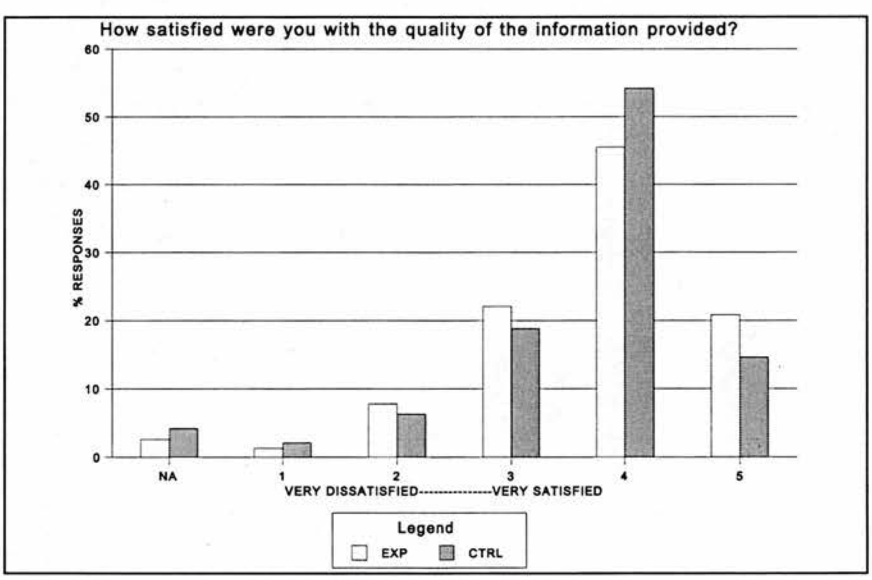


Figure B-9: Satisfaction with quality of information

5.8.1 If not satisfied, to what extent was this due to: a) the technology?

very much 5 4 3 2 1 not at all

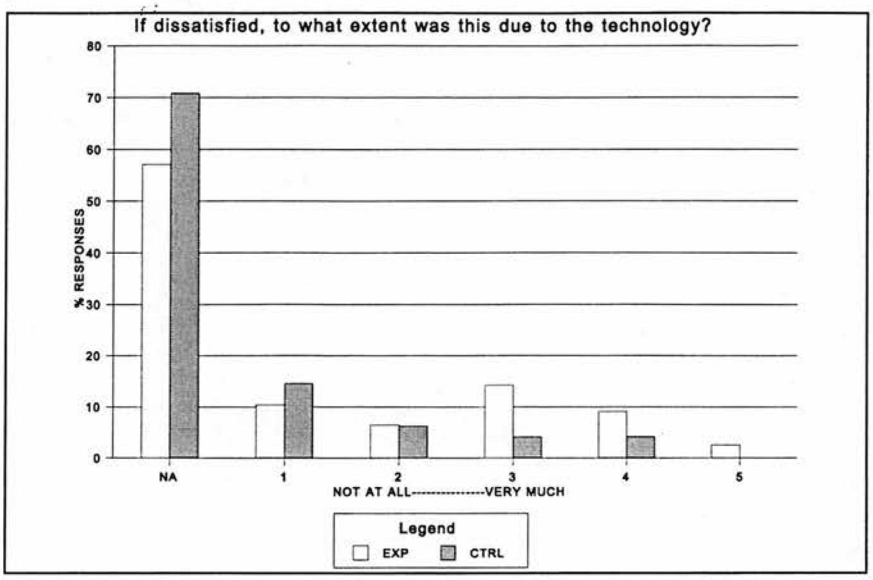


Figure B-10: Dissatisfaction due to the technology.

b) the content material?

very much 5 4 3 2 1 not at all

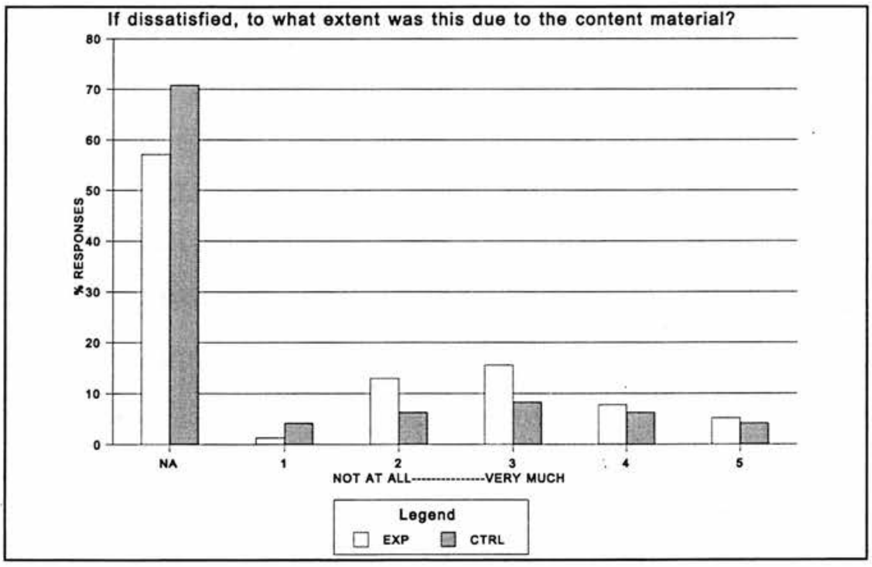


Figure B-11: Dissatisfaction due to the content material.

5.9 Did you have to concentrate more than on the normal fieldtrip?

yes, most of the time 5 4 3 2 1 no/seldom

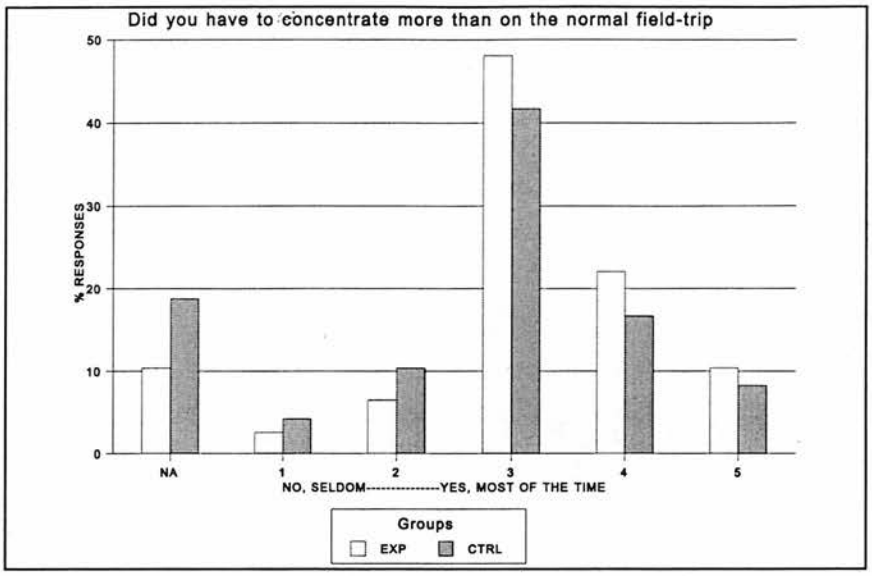


Figure B-12: Level of concentration

HINDRANCES

5.10 In your opinion, was the VE hindered (tick any that apply):

- by too many static pictures
- by too many animated pictures
- by too much text
- by poor indication of the students location at the site
- by slow down-loading of images
- by characteristics of the interface
- by other characteristics

FUTURE IMPROVEMENTS

5.11 What would you like to see improved in future versions of the VE?

- more panoramic pictures
- more textual information
- more navigational aids to improve orientation
- opportunities to take notes
- opportunities to practice sketches
- more student interaction
- opportunities to ask questions the interface

5.12 Did you have enough computer experience to handle the system adequately?

yes definitely 5 4 3 2 1 no, definitely not

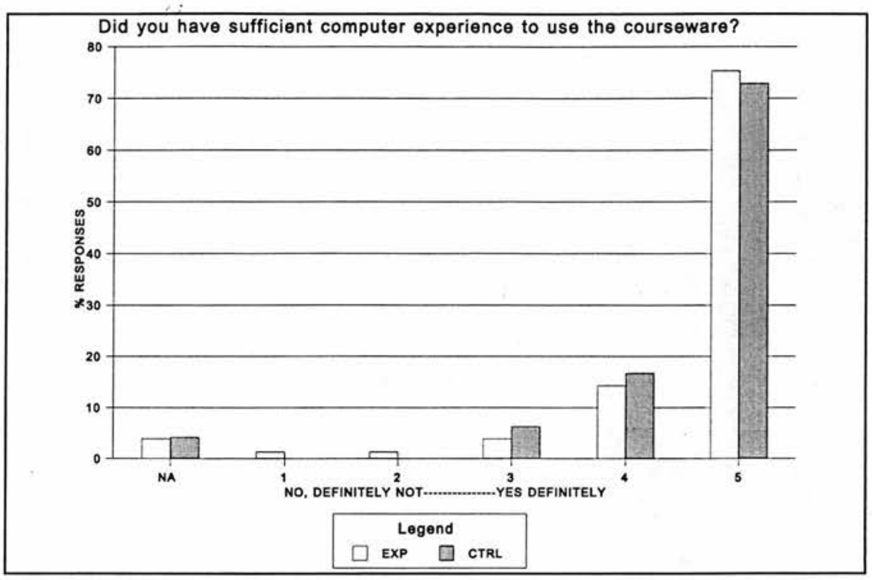


Figure B-13: Experience for using the courseware.

5.13 If additional VEs were made available for other field excursions, how much time would you be prepared to spend on one?

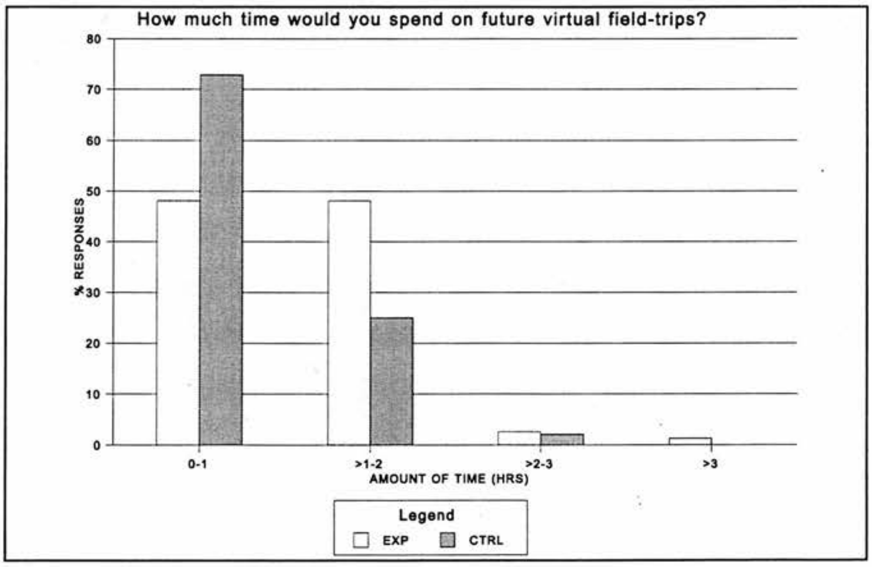


Figure B-14: Time spent on future virtual field-trips.

5.14 What did you gain most from this VE?

- spatial layout of the site

- an idea of the tasks that are expected to be carried out at the site (for example, sketching)
- knowledge of the geological features that will be expected to be found on site
- features of importance to pay attention to
- connecting theory (from the classroom) with practice (on the fieldtrip)
- visualising the site and associated features - making recognition of the features easier
- contextual knowledge of the site (background/history)

5.15 Which features of the VE are especially good or bad?

POSITIVE FEATURES OF THE VE:

- use of photographs and explanations
- examples of field sketches
- detail of certain features

NEGATIVE FEATURES OF THE VE:

- lack of any overview map of the site
- difficulty of orientation tests
- lack of adequate navigation/location cues - problems of disorientation
- overuse of the computer for teaching geology

6 Student sketches

GROUPS	**N**	**MEAN**	**SD**
SAT	81	3.52	1.07
SUN	62	3.48	.84

Table B-5: Means and standard deviations of students sketching scores

This demonstrated no significant difference between the Saturday and Sunday groups in their performance on the first sketch of the unconformity $t(140.86)=0.22$, ns.

7 Student notes

GROUPS	**N**	**MEAN**	**SD**
SAT	81	14.79	2.87
SUN	62	14.95	2.10

Table B-6: Means and standard deviations of the students scores on the Geology 1 Assignment sheet

The t-test found no significant difference between the performance of the Saturday and Sunday groups on the Assignment sheet $t(140.74)=-0.39$, ns.

APPENDIX C

EXPERIMENT 2 DATA: FIRST HOLYROOD PARK EVALUATION

1 Geo-pretest

GROUP	A/SEAT, CRAGS	OTHER	DON'T KNOW
MM	8	0	7
VR	7	2	5
CTRL	6	4	0
TOTAL	**25**	**6**	**12**

Table C-1: Index of information on the Geo-pretest

2 Revised Minnesota Paper Form Board test (RMPFB)

GROUPS	MEAN	SD	VARIANCE	CASES
MM	18.113	2.640	6.970	16
VR	21.360	3.709	13.755	15
CTRL	19.140	2.199	4.836	10

Table C-2: Means and SD's of the RMPFB scores for the three groups

3 Orientation Tasks

3.1 Landmark knowledge

GROUP	MM		VR		CTRL	
	MEAN	SD	MEAN	SD	MEAN	SD
LMARK 1	1.69	1.02	1.83	1.03	1.00	0.87
LMARK 2	4.50	1.51	4.25	1.71	5.44	2.13
LMARK 3	6.69	2.72	6.17	2.69	7.78	1.48
TOTAL	4.29		4.08		4.74	

Table C-3: Means and SD's of student scores on the landmark knowledge test

3.2 Route knowledge

GROUP	MM		VR		CTRL	
	MEAN	SD	MEAN	SD	MEAN	SD
ROUTE 1	2.25	1.00	1.67	0.99	2.33	0.87
ROUTE 2	2.00	0.88	1.67	0.99	2.11	1.17
ROUTE 3	2.15	0.56	2.00	0.85	2.11	0.60
TOTAL	2.13		1.78		2.18	

Table C-4: Means and SD's of the subject's scores in the route knowledge task

3.3 Survey knowledge

GROUP	MM		VR		CTRL	
	MEAN	SD	MEAN	SD	MEAN	SD
SURVEY 1	2.20	1.15	2.00	1.49	1.89	1.62
SURVEY 2	2.71	2.20	3.60	1.65	3.67	2.60
SURVEY 3	4.85	3.56	4.20	3.23	5.00	3.00
TOTAL	3.25		3.27		3.52	

Table C-5: Means and SD's of the subject's scores in the survey knowledge task

3.4 Transformation task A

GROUP	MM		VR		CTRL	
	MEAN	SD	MEAN	SD	MEAN	SD
TRANSA 123	1.75	0.93	2.08	0.79	2.22	0.83
TRANSA 456	1.86	0.95	2.33	0.49	2.00	1.00
TRANSA 789	2.15	0.99	2.08	0.90	2.50	0.85
TOTAL	1.92		2.16		2.24	

Table C-6: Means and standard deviations of subject's performance in the transformation A task

3.5 Transformation task B

GROUP	MM		VR		CTRL	
	MEAN	SD	MEAN	SD	MEAN	SD
TRANSB 123	2.06	0.68	2.50	0.52	1.78	0.44
TRANSB 456	2.21	0.89	2.33	0.65	2.33	0.71
TRANSB 789	2.77	0.60	3.00	0.00	2.63	0.74
TOTAL	2.35		2.61		2.25	

Table C-7: Means and standard deviations of subject's performance in the transformation B task

4 Knowledge Tasks

4.1 Geonames task

GROUP	MM		VR		CTRL	
	MEAN	SD	MEAN	SD	MEAN	SD
GEONAME1	9.06	1.00	9.00	1.28	9.11	0.93
GEONAME2	8.86	1.17	6.08	1.92	7.60	3.24
TOTAL	8.96		7.54		8.36	

Table C-8: Means and standard deviations of subject performance in the geo-names task

4.2 Geology conceptual knowledge task

GROUP	MM		VR		CTRL	
	MEAN	SD	MEAN	SD	MEAN	SD
MCQ1	1.31	1.02	2.67	1.50	2.11	0.93
MCQ2	2.79	1.12	3.67	0.99	3.33	1.23
MCQ3	2.85	0.90	3.08	1.38	2.56	1.51
TOTAL	2.32		3.14		2.67	

Table C-9: Means and standard deviations of subject performance in the geo-conceptual knowledge task

	Geo-name	Mcq	Lmark	Route	Survey	Transa	Transb	Rmpfb
Geo-name		NS	0.31**	0.22*	NS	NS	NS	.29*
Mcq	NS		NS	0.28*	NS	.21 P=.06	NS	NS
Lmark	0.31**	NS		NS	.36*	NS	.30*	-.26 P=.059
Route	0.22*	0.28*	NS		NS	NS	-.25 P=.06	NS
Survey	NS	NS	.36*	NS		NS	NS	NS
Transa	NS	.21 P=.06	NS	NS	NS		.33*	NS
Transb	NS	NS	.30*	-.25 P=.06	NS	.33*		NS
Rmpfb	.29*	NS	-.26 P=.059	NS	NS	NS	NS	

*P<0.05 **P<0.01

Table C-10: Correlation matrix for all tests - (significance analysed using partial correlation coefficients, all significance 1-tailed)

5 Native and Non-native English Speakers

GROUP / TEST	NON NATIVE (GRP 1)	NATIVE (GAP 2)	SIG
LMARK 1	2.09	1.34	*
LMARK2	4.40	4.76	ns
LMARK3	5.00	7.54	**
ROUTE 1	1.55	2.31	*
ROUTE 2	1.60	2.04	ns
ROUTE 3	2.00	2.13	ns
SURVEY 1	1.56	2.24	ns
SURVEY 2	3.50	3.12	ns
SURVEY 3	4.44	4.58	ns
TRANS A13	1.64	2.12	ns
TRANS A46	2.10	2.04	ns
TRANS A79	2.10	2.25	ns
TRANS B13	2.27	2.08	ns
TRANS B46	2.10	2.36	ns
TRANS B79	3.00	2.75	P=0.06, ns
GEONAMES 1	8.55	9.27	P=O.O6, ns
GEONAMES 2	6.50	8.32	**
MCQ 1	1.73	2.04	ns
MCQ 2	2.80	3.40	ns
MCQ 3	2.70	2.92	ns

*P<0.05, **P<0.01

Table C-11: Mean performance across all tests between native and non-native English speakers.

GROUP	VR	MM
LMARK1	2.29	1.75
LMARK2	4.57	4.00
LMARK3	5.57	3.67
ROUTE1	1.29	2.00
ROUTE2	1.57	1.67
ROUTE3	1.83	2.00
SURVEY1	2.00	1.00
SURVEY2	4.00	2.67
SURVEY3	3.50	6.33
GEONAMES1	8.57	8.50
GEONAMES2	5.86	8.00
MCQ1	2.14	1.00
MCQ2	3.29	1.67
MCQ3	2.71	2.67

Table C-12: Mean performance across all tests for non-native English speakers.

GROUP	VR	MM	CTRL
LMARK1	1.20	1.67	1.00
LMARK2	4.57	4.00	5.44
LMARK3	7.00	7.60	7.78
ROUTE1	2.20	2.33	2.33
ROUTE2	1.80	2.09	2.11
ROUTE3	2.00	2.20	2.11
SURVEY1	2.00	2.64	1.89
SURVEY2	3.20	2.73	3.56
SURVEY3	4.20	4.56	5.00
GEONAMES1	9.60	9.25	9.11
GEONAMES2	6.40	8.91	8.50
MCQ1	3.40	1.42	2.11
MCQ2	4.20	3.09	3.33
MCQ3	3.60	2.90	2.56

Table C-13: Mean performance across all tests native English speakers.

5 How well are you able to visualise in your mind: a) the entire area of Holyrood Park: [not at all 1 2 3 4 5 very clearly (photographic)]

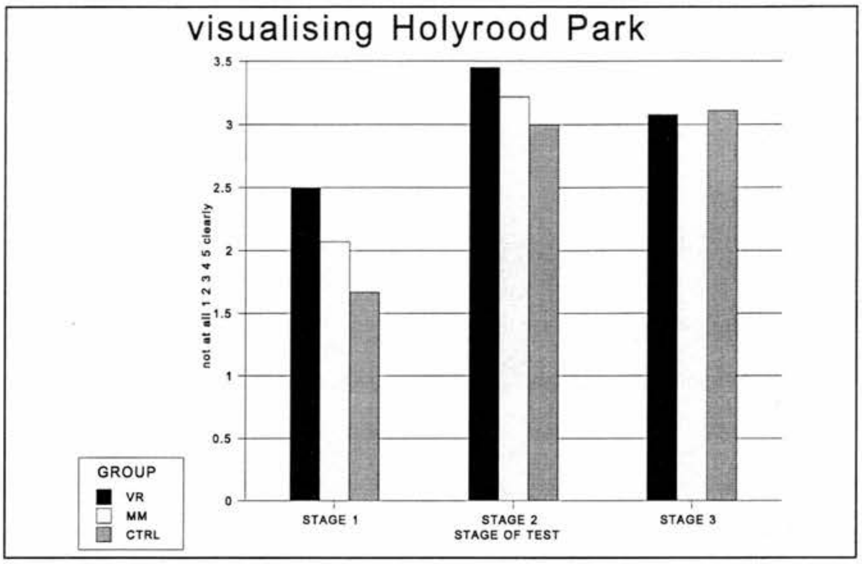


Figure C-1: Mean ratings across all groups for all three stages of experiment

b) the location of each of the geological features: [not at all 1 2 3 4 5 very clearly (photographic)]

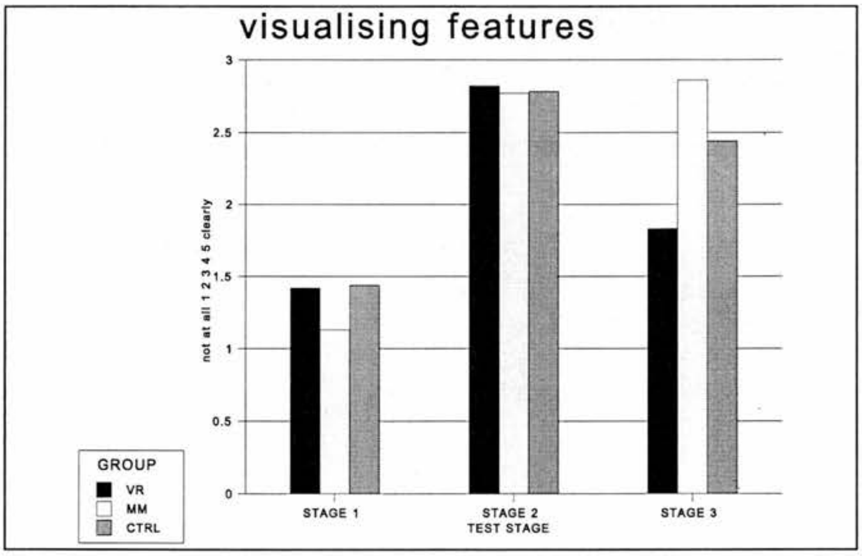


Figure C-2: Mean ratings across all groups for all three stages of experiment

APPENDIX D

EXPERIMENT 4 DATA: THE SECOND HOLYROOD PARK EVALUATION

1. Overall results

TEST	VR (MEAN / SD)	MM (MEAN / SD)	CTRL (MEAN / SD)	SIG
LMARK	**2.22** / 1.64	**1.80** / 1.22	**1.33** / 1.11	NS
ROUTE	**1.77** / .83	**1.90** / 1.10	**1.22** / 1.09	NS
SURVEY	**3.33** / 1.50	**2.40** / 1.50	**3.0** / 1.73	NS
NAMES	**9.33** / 1.00	**9.20** / .91	**8.11** / 2.14	NS
QUIZ	**5.22** / 1.98	**6.10** / .99	**5.33** / 1.58	NS

Table D-1: Means and standard deviations for all tests and the significance achieved

	GROUP									**GROUP TOTAL**	
	VR			**MM**			**CTRL**			**MEAN**	**N**
	M	**SD**	**N**	**M**	**SD**	**N**	**M**	**SD**	**N**		
HI-SPATIAL											
LMARK	**2.17**	1.33	6	**2.40**	1.14	5	**1.67**	1.15	3	**2.14**	**14**
ROUTE	**1.83**	.41	6	**1.80**	1.30	5	**2.00**	1.00	3	**1.86**	**14**
SURVEY	**3.50**	1.52	6	**3.20**	1.48	5	**2.67**	2.52	3	**3.21**	**14**
NAMES	**9.50**	1.22	6	**9.40**	.55	5	**9.67**	.58	3	**9.50**	**14**
QUIZ	**5.50**	1.64	6	**6.20**	.84	5	**5.33**	.58	3	**5.71**	**14**
LO-SPATIAL											
LMARK	**2.33**	2.52	3	**1.20**	1.10	5	**1.17**	1.17	6	**1.43**	**14**
ROUTE	**1.67**	1.53	3	**2.00**	1.00	5	**.83**	.98	6	**1.43**	**14**
SURVEY	**3.00**	1.73	3	**1.60**	1.14	5	**3.17**	1.47	6	**2.57**	**14**
NAMES	**9.00**	.00	3	**9.00**	1.22	5	**7.33**	2.25	6	**8.29**	**14**
QUIZ	**4.67**	2.89	3	**6.00**	1.22	5	**5.33**	1.97	6	**5.43**	**14**

GROUP MEANS											
LMARK	2.22	1.64	9	1.80	1.23	10	1.33	1.12	9	1.79	28
ROUTE	1.78	.83	9	1.90	1.10	10	1.22	1.09	9	1.64	28
SURVEY	3.33	1.50	9	2.40	1.51	10	3.00	1.73	9	2.89	28
NAMES	9.33	1.00	9	9.20	.92	10	8.11	2.15	9	8.89	28
QUIZ	5.22	1.99	9	6.10	.99	10	5.33	1.58	9	5.57	28

Table D-2: Median split of means across all tests for hi-LO spatial x group

GROUP										
		VR			MM			CTRL		
		M	**SD**	**N**	**M**	**SD**	**N**	**M**	**SD**	**N**
HI SPATIAL	**NONSPAT**	**.18**	.72	6	**.37**	.29	5	**.18**	.33	3
	SPATIAL	**.29**	.57	6	**.27**	.51	5	**.04**	.38	3
LO SPATIAL	**NONSPAT**	**-.25**	.93	3	**.18**	.61	5	**-.60**	1.32	6
	SPATIAL	**.17**	1.20	3	**-.30**	.40	5	**-.36**	.54	

Table D-3: Z scores for GROUP X SPATIAL. / NONSPATIAL

APPENDIX E

EXPERIMENT 6 DATA: THE THIRD HOLYROOD PARK EVALUATION

1. Pretests

1.1 Paper-folding test (PFT)

	MEAN	SD
VRALL	11.90	4.46
VRSPAT	14.30	4.28
VRMETA	13.50	3.13
VR (CTRL)	13.60	3.44
MMALL	13.70	3.03
MMSPAT	9.70	4.58
MMETA	12.30	3.37
MM(CTRL)	13.00	3.53

Table E-1: Mean results for PFT

Mean score across all groups = 12.75
One way anova found no significant differences between the groups: $F(7,88)=1.79$, NS
Median split into High and Low-spatial subjects, median = 12.80

1.1.1 Comparison between males and females:

	MEAN	SD
MALES	13.83	3.8
FEMALES	11.68	3.7

Table E-2: Comparison between males and females on PFT

An independent t-test indicated a significant difference between males and females: $t(94)=2.81$, $p<0.01$

1.2 Study Preference Questionnaire (SPQ)

GROUP	FREQUENCY	PERCENTAGE
HOLIST	44	45.8
SERIALIST	52	54.2

Table E-5: Numbers of each type of subject in experiment

	HOLIST	SERIALIST
VRALL	8	4
VRSPAT	7	5
VRMETA	6	6
VR(CTRL)	4	8
MMALL	6	6
MMSPAT	7	5
MMETA	2	10
MM(CTRL)	4	8

Table E-6: Numbers of HOLISTS and SERIALISTS for each group in experiment

2 Landmark test

GROUP	RECOGNISE		IDENTIFY		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	4.83	2.01	1.73	2.43	6.57	3.76
VRSPAT	4.88	1.54	3.58	5.34	8.47	6.67
VRMETA	6.27	1.47	2.91	2.59	9.18	3.20
VR (CTRL)	5.72	1.52	2.23	2.98	7.95	4.38
MMALL	3.02	1.48	-.050	1.35	2.97	2.45
MMSPAT	3.05	1.62	-.66	1.84	2.38	2.49
MMETA	4.16	1.85	.01	2.03	4.17	3.64
MM(CTRL)	4.83	1.35	.25	2.17	5.09	3.23

Table E-7: Comparisons of means across all groups

RECOGNISE: One way anova [$F(7,88) = 6.05$, $p<0.01$], Post-hoc Tukey-HSD with α=.05:
VRMETA x MMALL
VR (CTRL) x MMALL
VRMETA x MMSPAT
VR (CTRL) x MMSPAT
VRMETA x MMETA

IDENTIFY: One way anova [$F(7,88) = 3.69$, $p<0.01$], Post-hoc Tukey-HSD with α=.05:
VRSPAT x MMSPAT
VRSPAT x MMALL

COMBINED SCORE: One way anova [$F(7,88) = 5.15$, $p<0.01$], Post-hoc Tukey-HSD with α=.05:
VRMETA x MMSPAT
VRSPAT x MMSPAT
VR (CTRL) x MMSPAT
VRSPAT x MMALL
VRMETA x MMETA
VRMETA x MMALL

GROUP	RECOGNISE		IDENTIFY		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VR	5.43	1.71	2.61	3.49	8.04	4.65
MM	3.77	1.73	-.11	1.85	3.66	3.09

Table E-8: Independent t-test comparison between VR and MM for LMARK dataset

RECOGNISE: Independent t-test [t(94) = 4.73, p<0.01]
IDENTIFY: Independent t-test [t(94) = 4.78, p<0.01]
COMBINED SCORE: Independent t-test [t(94) = 5.45, p<0.01]

2.1 Landmark test (high-spatial subjects)

GROUP	RECOGNISE		IDENTIFY		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	4.06	1.36	2.83	2.64	6.90	3.74
VRSPAT	5.20	1.68	4.29	6.40	9.50	7.84
VRMETA	6.14	.85	2.22	1.64	8.36	2.09
VR (CTRL)	6.00	.98	2.96	2.08	8.96	2.84
MMALL	2.71	1.89	.21	1.31	2.92	2.99
MMSPAT	4.00	1.52	-.42	.74	3.58	1.90
MMETA	3.72	1.54	-.17	1.85	3.54	3.03
MM(CTRL)	4.86	.64	1.20	2.63	6.07	3.16

Table E-9: Comparisons across all groups for HISPATIAL subjects

RECOGNISE: One way anova [F(7,40) = 4.8, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRSPAT X MMALL
VRMETA X MMALL
VR (CTRL) X MMALL
IDENTIFY: One way anova[F(7,40) = 1.7, NS]
COMBINED SCORE: One way anova [F(7,40) = 2.48, NS]

2.2 Landmark test (low -spatial subjects)

GROUP	RECOGNISE		IDENTIFY		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	5.38	2.32	.95	2.11	6.33	4.05
VRSPAT	4.25	1.13	2.17	2.30	6.42	3.38
VRMETA	6.46	2.19	3.87	3.52	10.33	4.33
VR (CTRL)	5.33	2.14	1.20	3.96	6.54	6.04
MMALL	3.46	.50	-.42	1.48	3.04	1.75
MMSPAT	2.74	1.61	-.74	2.12	1.99	2.63
MMETA	4.61	2.17	.19	2.35	4.80	4.36
MM(CTRL)	4.80	1.76	-.42	1.65	4.38	3.33

Table E-10: Comparisons across all groups for LOSPATIAL subjects

RECOGNISE: One way anova [$F(7,40) = 2.58$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT
IDENTIFY:
One way anova [$F(7,40) = 2.24$, $P<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT
COMBINED SCORE
One way anova [$F(7,40) = 2.71$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT

2.3 Landmark test (**HOLISTIC** subjects)

GROUP	RECOGNISE		IDENTIFY		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	5.04	2.43	1.43	2.62	6.47	4.59
VRSPAT	4.38	1.02	1.27	2.20	5.65	2.74
VRMETA	5.75	.68	1.80	.60	7.55	.71
VR (CTRL)	6.44	1.29	3.15	3.22	9.60	4.44
MMALL	2.55	1.89	.56	1.52	3.12	3.34
MMSPAT	2.80	1.79	-1.26	2.15	1.54	2.82
MMETA	5.00	.47	1.43	1.56	6.43	2.04
MM(CTRL)	4.83	1.66	-.23	1.94	4.59	3.5

Table E-11: Comparisons across all groups for HOLISTIC subjects

RECOGNISE: One way anova [$F(7,36) = 3.73$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMALL
VR(CTRL) x MMSPAT
IDENTIFY: One way anova [$F(7,36) = 2.13$, $p<0.06$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMSPAT
COMBINED SCORE: One way anova [$F(7,36) = 3.21$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMSPAT

2.4 Landmark test (**SERIALIST** subjects)

GROUP	RECOGNISE		IDENTIFY		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	4.41	.87	2.35	2.20	6.77	1.60
VRSPAT	5.60	1.97	6.83	6.98	12.43	8.81
VRMETA	6.54	1.72	3.46	3.05	10.00	3.68
VR (CTRL)	5.00	1.47	1.30	2.67	6.30	4.00
MMALL	3.50	.86	-.66	.896	2.83	1.39
MMSPAT	3.40	1.47	.17	.96	3.57	1.46
MMETA	4.00	2.00	-.27	2.05	3.72	3.79
MM(CTRL)	4.83	1.30	.50	2.36	5.33	3.30

Table E-12: Comparisons across all groups for SERIALIST subjects

RECOGNISE: One way anova [$F(7,44) = 3.09$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA x MMALL
VRMETA x MMSPAT
VRMETA x MMETA
IDENTIFY: One way anova [$F(7,44) = 4.01$, $p<0.065$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA x MMALL
VRMETA x MMSPAT
VRMETA x MMETA
VRMETA x MM(CTRL)
COMBINED SCORE: One way anova [$F(7,44) = 4.21$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT x MMALL
VRMETA x MMALL
VRSPAT x MMSPAT
VRSPAT x MMETA
VRMETA x MMETA
INTERACTION EFFECT: Three-way anova [$F(7,71) = 2.181$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
GROUP X HOL1SER2
INTERPRETATION: VE's benefit holistic learners more than do MM environments

3. Route test

	MEAN	SD
VRALL	5.23	4.51
VRSPAT	6.23	3.07
VRMETA	5.35	3.05
VR(CTRL)	4.57	4.29
MMALL	6.79	4.18
MMSPAT	4.90	3.07
MMETA	6.56	2.22
MM(CTRL)	5.12	3.53

Table E-13: Comparisons of means across all groups
One way anova: [$F(7,88) = 0.63$, NS]

	MEAN	SD
VR	5.35	3.72
MM	5.85	3.33

Table E-14: Independent t-test comparison between VR and MM for the ROUTE dataset

Independent t-test: [t(94) = -.69, NS]

DESCRIPTIVE STATS AND ONE WAYS ANOVAS ACROSS ALL GROUPS UNDER HI SPATIAL SUBJECTS

3.1 Route text (high-spatial subjects)

	MEAN	SD
VRALL	4.81	3.46
VRSPAT	7.01	3.23
VRMETA	5.35	2.42
VR(CTRL)	4.97	5.07
MMALL	7.63	3.57
MMSPAT	5.79	2.03
MMETA	7.56	1.37
MM(CTRL)	2.95	3.31

Table E-15: Comparisons across all groups for HISPATIAL subjects

One way anova: [F(7,40) = 1.33, NS],

3.2 Route text (low -spatial subjects)

	MEAN	SD
VRALL	5.54	5.39
VRSPAT	4.68	2.30
VRMETA	5.35	4.09
VR(CTRL)	4.02	3.39
MMALL	5.61	5.09
MMSPAT	4.61	3.39
MMETA	5.57	2.58
MM(CTRL)	6.68	2.97

Table E-16: Comparisons across all groups for LOSPATIAL subjects

One way anova: [F(7,40) = 0.28, NS]

3.3 Route text (**HOLISTIC** subjects)

	MEAN	SD
VRALL	4.35	4.25
VRSPAT	4.97	1.83
VRMETA	7.01	2.74
VR(CTRL)	4.90	5.29
MMALL	9.11	2.71
MMSPAT	4.21	3.79
MMETA	7.34	2.82
MM(CTRL)	6.01	1.71

Table E-17: Comparisons across all groups for HOLISTIC subjects

One way anova: [F(7,36) = 1.38, NS]

3.4 Route text (**SERIALIST** subjects)

	MEAN	SD
VRALL	7.01	5.13
VRSPAT	8.01	3.76
VRMETA	4.51	3.01
VR(CTRL)	4.24	3.51
MMALL	4.46	4.26
MMSPAT	5.88	1.51
MMETA	6.41	2.24
MM(CTRL)	4.68	4.20

Table E-18: Comparisons across all groups for SERIALIST subjects

One way anova: [F(7,44) = 0.93, NS]

4. SURVEY TEST

GROUP	EGO		GEO		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	.66	1.34	1.84	1.30	2.50	1.80
VRSPAT	.97	1.72	1.93	2.16	2.91	3.30
VRMETA	.56	1.20	1.74	1.81	2.30	2.10
VR (CTRL)	.35	.83	1.84	1.54	2.19	1.72
MMALL	1.18	1.20	2.02	1.87	4.05	3.74
MMSPAT	.45	.89	2.30	2.05	2.76	2.51
MMETA	.87	1.25	2.02	1.80	2.90	2.66
MM(CTRL)	1.50	1.30	2.49	1.93	3.99	3.04

Table E-19: Comparisons of means across all groups

EGO: One way anova: [F(7,88) = 1.17, NS]
GEO: One way anova: [F(7,88) = 0.23, NS]
COMBINED SCORE: One way anova: [F(7,88) = 0.82, NS]

GROUP	EGO		GEO		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VR	0.64	1.29	1.84	1.68	2.48	2.26
MM	1.01	1.2	2.21	1.87	3.42	2.99

Table E-20: Independent t-test comparison between VR and MM

EGO: Independent t-test [t(94) = -1.43, NS]
GEO: Independent t-test [t(94) = -1.03, NS]
COMBINED SCORE: Independent t-test [t(94) = -1.75, NS]

4.1 Survey text (**high-spatial** subjects)

GROUP	EGO		GEO		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	1.25	1.04	1.28	1.37	2.53	2.01
VRSPAT	1.34	1.69	2.12	2.66	3.46	3.87
VRMETA	-.10	.94	1.92	1.92	1.81	1.80
VR (CTRL)	.60	.94	2.56	1.36	3.16	1.46
MMALL	1.67	1.33	1.76	1.69	3.52	3.38
MMSPAT	1.08	.72	2.77	2.33	3.85	1.90
MMETA	1.29	1.46	2.77	2.41	4.06	3.39
MM(CTRL)	1.50	1.97	2.84	1.87	4.34	3.79

Table E-21: Comparisons across all groups for HISPATIAL subjects
EGO: One way anova: [F(7,40) = 1.23, NS]; **GEO:** One way anova [F(7,40) = 0.43, NS]; **COMBINED SCORE:** One way anova [F(7,40) = 0.48, NS]

4.2 Survey text (**low-spatial** subjects)

GROUP	EGO		GEO		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	.25	1.44	2.24	1.19	2.49	1.74
VRSPAT	.25	1.76	1.56	.56	1.81	1.58
VRMETA	1.50	.88	1.50	1.84	3.00	2.50
VR (CTRL)	.00	.55	.83	1.27	.83	.98
MMALL	.50	.55	2.40	2.24	4.80	4.48
MMSPAT	.25	.88	2.15	2.07	2.40	2.68
MMETA	.45	.94	1.28	.00	1.73	.94
MM(CTRL)	1.50	.72	2.24	2.08	3.74	2.68

Table E-22: Comparisons across all groups for LOSPATIAL subjects

EGO: One way anova [F(7,40) = 1.96, NS]
GEO: One way anova [F(7,40) = 0.65, NS]
COMBINED SCORE: One way anova [F(7,40) = 1.36, NS]

4.3 Survey text (**HOLISTIC** subjects)

GROUP	EGO		GEO		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	.40	1.23	1.56	1.43	1.96	1.86
VRSPAT	.07	1.33	1.44	1.19	1.51	1.53
VRMETA	.56	1.19	.72	1.44	1.28	1.09
VR (CTRL)	.04	.94	1.09	1.30	1.13	1.17
MMALL	1.29	1.46	3.33	1.79	6.66	3.58
MMSPAT	.42	.86	2.72	1.90	3.14	2.56
MMETA	.25	1.76	.16	1.58	.41	3.35
MM(CTRL)	1.18	1.57	2.68	2.48	3.86	3.92

Table E-23: Comparisons across all groups for HOLISTIC subjects

EGO: One way anova [F(7,36) = 0.78, NS]
GEO: One way anova [F(7,36) = 1.98, NS]
COMBINED SCORE: One way anova [F(7,36) = 3.63, p<0.01], Post-hoc Tukey-HSD with α=.05:
MMALL x VRSPAT
MMALL x VRMETA
MMALL x VR(CTRL)
MMALL x MMETA

4.4 Survey text (**SERIALIST** subjects)

GROUP	EGO		GEO		COMBINED SCORE	
	MEAN	SD	MEAN	SD	MEAN	SD
VRALL	1.18	1.57	2.40	.91	3.58	1.20
VRSPAT	2.25	1.42	2.62	3.10	4.87	4.27
VRMETA	.56	1.29	2.26	1.83	2.82	2.35
VR (CTRL)	.66	.64	2.58	1.48	3.25	1.56
MMALL	1.08	1.02	.72	.61	1.44	1.22
MMSPAT	.50	1.04	1.72	2.32	2.22	2.62
MMETA	1.00	1.20	2.40	1.66	3.40	2.40
MM(CTRL)	1.65	1.23	2.40	1.79	4.05	2.82

Table E-24: Comparisons across all groups for SERIALIST subjects

EGO: One way anova [F(7,44) = 1.45, NS]
GEO: One way anova [F(7,44) = 0.72, NS]
COMBINED SCORE: One way anova [F(7,44) = 1.05, NS]
INTERACTIONS:
3-way anova for all groups using scrcorr data:
GROUP X HOL1SER2 [F(7,71) = 3.99, p<0.05]
Interpretation: SERIALISTS perform better than HOLISTS in VR but not in MM
HI1LO2 X HOL1SER2 [F(1,71) = 5.59, p<0.05]
Interpretation: For HISPATIAL subjects SERIALISTS perform better than HOLISTS, this is reversed for LO-SPATIAL subjects
3-way anova for all groups using egocorr data:
GROUP X HI1LO2 [F(7,71) = 2.17, p<0.05]
Interpretation: HI-SPATIAL perform better than LO-SPATIAL in MM but not in VR. Results for MM are mixed
3-way anova for all groups using geocorr data:
GROUP X HOL1SER2 [F(7,71) = 2.44, p<0.05]
Interpretation: SERIALISTS perform better than HOLISTS in VR but not in MM. Results for MM are mixed
HI1LO2 X HOL1SER2 [F(1,71) = 3.86, p<0.05]
Interpretation: For HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, this is reversed for LO-SPATIAL subjects
3-way anova for the VR groups only using scrcorr data: [F(7,33) = 0.55, NS]
3-way anova for the VR groups only using egocorr data: [F(7,33) = 1.94, NS]
3-way anova for the VR groups only using geocorr data: [F(7,33) = 0.50, NS]

Significant main effect between HOLISTS and SERIALISTS is investigated further with independent t tests:

	EGO		GEO		COMBINED SCORES	
	MEAN	SD	MEAN	SD	MEAN	SD
HOLIST	0.25	1.1	1.29	1.29	1.53	1.47
SERIALIST	1.07	1.34	2.45	1.86	3.51	2.54

Table E-25: Independent t-test comparison of HOLIST and SERIALIST subjects.

EGO: Independent t-test [t(46) = -2.28, p<0.05]
GEO: Independent t-test [t(46) = -2.54, p<0.05]
COMBINED SCORES: Independent t-test [t(46) = -3.35, p<0.01]
INTERACTIONS:
3-way anova for the MM groups only using scrcorr data:
GROUP x HOL1SER2: [F(3,35) = 7.28, p<0.01]
Interpretation: HOLISTS outperform SERIALISTS for MMALL and MMSPAT groups, its reversed for MMMETA/MM groups
HI1LO2 x HOL1SER2 : [F(1,35) = 13.8, p<0.01]
Interpretation: Among HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, its reversed for LOSPATIAL subjects
3-way anova for the MM groups only using egocorr data:
HI1LO2 x HOL1SER2: [F(1,35) = 5.03, p<0.05]

Interpretation: Among HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, its reversed for LOSPATIAL subjects
3 way anova for the MM groups only using geocorr data
GROUP x HOL1SER2: [F(3,35) = 4.36, p<0.01]
Interpretation: HOLISTS outperform SERIALISTS for MMALL and MMSPAT groups, its reversed for MMMETA /MM groups
HI1LO2 x HOL1SER2: [F(1,35) = 8.67, p<0.01]
Interpretation: Among HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, its reversed for LO-SPATIAL subjects

5. Geological knowledge test

	MEAN	SD
VRALL	3.90	1.19
VRSPAT	4.40	1.98
VRMETA	3.80	1.30
VR(CTRL)	4.60	1.68
MMALL	4.20	1.60
MMSPAT	4.00	1.72
MMETA	4.20	1.90
MM(CTRL)	4.90	1.57

Table E-26: Comparisons of means across all groups
One way anova [F(7,88) = 0.61, NS]

	MEAN	SD
VR	4.18	1.6
MM	4.33	1.7

Table E-27: Independent t-test comparison between VR and MM

Independent t test comparison between VR and MM for the QUIZ dataset: [t(94) = -.45, NS]

5.1 Knowledge test (high-spatial subjects)

	MEAN	SD
VRALL	3.68	1.07
VRSPAT	4.25	1.97
VRMETA	3.80	1.00
VR(CTRL)	5.15	1.80
MMALL	3.88	1.67
MMSPAT	4.40	1.20
MMETA	5.40	1.17
MM(CTRL)	4.88	1.81

Table E-28: Comparisons across all groups for HISPATIAL subjects
One way anova: [F(7,40) = 1.05, NS]

5.2 Knowledge test (low -spatial subjects)

	MEAN	SD
VRALL	4.05	1.33
VRSPAT	4.70	2.27
VRMETA	3.80	1.65
VR(CTRL)	3.50	.60
MMALL	4.64	1.56
MMSPAT	3.86	1.90
MMETA	3.00	1.76
MM(CTRL)	4.91	1.52

Table E-28: Comparisons across all groups for LOSPATIAL subjects

One way anova: $[F(7,40) = 0.90, NS]$

5.3 Knowledge test (**HOLISTIC** subjects)

	MEAN	SD
VRALL	3.80	1.28
VRSPAT	4.05	2.26
VRMETA	3.80	1.54
VR(CTRL)	4.80	1.63
MMALL	5.00	1.46
MMSPAT	3.54	2.04
MMETA	4.40	3.39
MM(CTRL)	4.70	2.04

Table E-29: Comparisons across all groups for HOLISTIC subjects

One way anova: $[F(7, 36) = 0.51, NS]$

5.4 Knowledge test (**SERIALIST** subjects)

	MEAN	SD
VRALL	4.10	1.14
VRSPAT	4.88	1.61
VRMETA	3.80	1.28
VR(CTRL)	4.40	1.85
MMALL	3.40	1.40
MMSPAT	4.64	1.00
MMETA	4.16	1.77
MM(CTRL)	5.00	1.43

Table E-28: Comparisons across all groups for SERIALIST subjects

One way anova: [F(7, 44) = 0.85, NS]
INTERACTIONS:
3-way anova found almost significant interaction between:
HI1LO2SP X GROUP: [F(7, 71) = 2.06, p=.059]
Interpretation: HI-SPATIAL subjects in the VRMETA, VR, MMMETA, MM groups perform better than LO-SPATIAL subjects on this test while LO-SPATIAL subjects in the VRALL, VRSPAT, MMALL, MMSPAT groups perform slightly better than their HISPATIAL counterparts.

6. METAUSE (use of metacognitive features)

	MEAN	SD
VR	30.5	14.1
MM	27.7	9.4

Table E-29: Comparisons of means across VR and MM

	MEAN	SD
VRALL	32.5	15.4
VRMETA	28.6	13.02
MMALL	30.8	10.8
MMMETA	24.5	6.9

Table E-30: Comparisons of means across VRALL, VRMETA, MMALL, MMMETA

	MEAN	SD
HI-SPATIAL	30.1	13.1
LO-SPATIAL	28	10.7

Table E-31: Comparisons of means across HI/LOSPATIAL

	MEAN	SD
HOLIST	31.2	14.98
SERIALIST	27.6	9.1

Table E-32: Comparisons of means across HOLIST/SERIALIST's

	MEAN	SD
MALE	27.5	9.9
FEMALE	30.8	13.7

Table E-33: Comparisons of means across MALE/FEMALES

		VRALL		VRMETA		MMALL		MMMETA	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
LMARK	HIMETA	7.82	4.21	10.50	4.22	1.94	2.53	5.84	4.15
	LOMETA	4.81	2.38	7.86	.70	4.01	2.05	2.98	2.97
RECOG	HIMETA	5.28	2.55	6.61	1.28	2.61	2.01	4.93	2.12
	LOMETA	4.20	.73	5.94	1.69	3.44	.62	3.61	1.56
ID	HIMETA	2.54	2.45	3.89	3.22	-.66	.89	.91	2.18
	LOMETA	.61	2.13	1.92	1.43	.56	1.52	-.63	1.79
ROUTE	HIMETA	7.06	2.94	5.35	3.94	6.45	4.56	6.41	3.17
	LOMETA	2.69	5.40	5.35	2.22	7.12	4.17	6.68	1.53
SURVEY	HIMETA	1.69	1.81	2.85	1.97	2.93	2.20	2.95	1.94
	LOMETA	3.65	1.08	1.76	2.26	5.17	4.78	2.86	3.24
EGO	HIMETA	.25	1.02	.45	1.22	1.50	1.36	1.00	1.11
	LOMETA	1.25	1.62	.66	1.29	.87	1.04	.78	1.41
GEO	HIMETA	1.44	1.50	2.40	1.87	1.46	1.10	1.95	1.00
	LOMETA	2.40	.79	1.09	1.64	2.58	2.39	2.08	2.30
QUIZ	HIMETA	4.05	1.14	3.80	1.00	4.40	1.51	4.16	1.56
	LOMETA	3.68	1.36	3.80	1.65	4.00	1.80	4.22	2.23

Table E-34: Comparison between HI/LOMETA for all tests across VRALL, VRMETA, MMALL, MMMETA groups

HIMETA GROUP:
LMARK: One way anova [$F(3,20) = 5.28$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
RECOG: One way anova [$F(3,20) = 3.89$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
ID: One way anova [$F(3,20) = 4.23$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL

LOMETA GROUP:
LMARK: One way anova [$F(3,20) = 5.56$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
VRMETA X MMMETA
RECOG: One way anova [$F(3,20) = 4.81$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
VRMETA X MMMETA

7. VENAUSE (use of spatial features esp. Aerial images)

	MEAN	SD
VR	10.9	6.3
MM	23.8	7.9

Table E-35: Comparisons of means across VR and MM

	MEAN	SD
VRALL	10	3.3
VRSPAT	11.8	8.4
MMALL	24.1	8.8
MMSPAT	23.5	7.3

Table E-36: Comparisons of means across VRALL, VRSPAT, MMALL, MMSPAT

	MEAN	SD
HI-SPATIAL	15.04	10.3
LO-SPATIAL	19.5	8.6

Table E-37: Comparisons of means across HI/LOSPATIAL

	MEAN	SD
HOLIST	16.8	8.9
SERIALIST	18.2	10.7

Table E-38: Comparisons of means across HOLIST/SERIALIST's

COMPARISON OF THE PERFORMANCE OF THE HI- and LO-VENA-USE SUBJECTS ACROSS VRSPAT, MMALL AND MMSPAT CONDITIONS (VRALL NOT INCLUDED FOR HI-VENA DUE TO INSUFFICIENT NUMBERS)

		VRALL		VRSPAT		MMALL		MMSPAT	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
LMARK	HIVENA			11.13	11.31	2.78	2.58	2.37	2.74
	LOVENA	6.57	3.76	7.14	3.00	3.95	1.93	2.47	.78
RECOG	HIVENA			5.08	2.54	2.83	1.49	2.86	1.54
	LOVENA	4.83	2.01	4.79	.97	4.00	1.41	4.00	2.35
ID	HIVENA			6.05	8.78	-.05	1.49	-.49	1.92
	LOVENA	1.73	2.43	2.35	2.58	-.05	.52	-1.53	1.56
ROUTE	HIVENA			6.68	4.20	6.94	4.33	4.68	3.21
	LOVENA	5.23	4.51	6.01	2.66	6.01	4.70	6.01	2.82
SURVEY	HIVENA			4.18	4.73	4.80	3.65	2.66	2.64
	LOVENA	2.50	1.80	2.27	2.48	.32	.00	3.27	2.46
EGO	HIVENA			1.50	2.28	1.25	1.29	.375	.922
	LOVENA	.66	1.34	.71	1.48	.87	.88	.87	.88
GEO	HIVENA			2.68	2.80	2.40	1.82	2.28	2.20
	LOVENA	1.84	1.30	1.56	1.86	.16	.00	2.40	1.58
QUIZ	HIVENA			5.60	2.19	4.52	1.54	4.16	1.77
	LOVENA	3.90	1.19	3.80	1.69	2.60	.84	3.20	1.69

Table E-39: Comparison of the performance of HI/LOVENA use subjects across VRSPAT, MMALL, MMSPAT, conditions (VRALL not included for HIVENA due to insufficient numbers)

LMARK:
One way anova [$F(2,21) = 5.03$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT X MMALL
VRSPAT X MMSPAT
ID:
One way anova [$F(2,21) = 4.96$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:

VRSPAT X MMALL
VRSPAT X MMSPAT

NO ANOVA COMPARISONS WERE SIGNIFICANT FOR LOVENA PERFORMANCE

		VR ALL	VR SPAT	VR META	VR (CTRL)	MM ALL	MM SPAT	MM META	MM (CTRL)
RECOG	**HI**		5.08	6.27	5.72	2.83	2.86	4.16	4.83
	LO	4.83	4.79	6.27	5.72	4.00	4.00	4.16	4.83
ID	**HI**		6.05	2.91	2.23	-.05	-.49	.011	.25
	LO	1.73	2.35	2.91	2.23	-.05	-1.53	.011	.25
ROUTE	**HI**		6.68	5.35	4.57	6.94	4.68	6.56	5.12
	LO	5.23	6.01	5.35	4.57	6.01	6.01	6.56	5.12
EGO	**HI**		1.50	.56	.35	1.25	.375	.87	1.50
	LO	.66	.71	.56	.35	.87	.87	.87	1.50
GEO	**HI**		2.68	1.74	1.84	2.40	2.28	2.02	2.49
	LO	1.84	1.56	1.74	1.84	.16	2.40	2.02	2.49
QUIZ	**HI**		5.60	3.80	4.60	4.52	4.16	4.20	4.90
	LO	3.90	3.80	3.80	4.60	2.60	3.20	4.20	4.90

Table E-40: Means of HI/LOVENA subjects with subjects from other conditions which acted as controls

HIVENA VR: Independent t test
QUIZ: VRSPAT X VRMETA [$t(14)= 2.03$, $P=0.062$]
HIVENA MM COMPARISON WITH CONTROLS ACROSS TESTS
RECOG: MMSPAT X MM (CTRL) [$t(20)= -3.18$, $P=0.05$]
EGO: MMSPAT X MM (CTRL) [$t(20)= -2.29$, $P=0.05$]

8. QUESTIONNAIRE DATA

	MEAN	SD
VRALL	4.08	.51
VRSPAT	3.58	1.08
VRMETA	3.08	.79
VR(CTRL)	3.66	.98
MMALL	3.91	.66
MMSPAT	3.41	.51
MMETA	3.58	.79
MM(CTRL)	3.41	.79
OVERALL	3.59	.81

Table E-41: Ratings of enjoyment of field excursion from 1 to 5 (1=didn't enjoy / 5= enjoyed very much)

	MEAN	SD
VRALL	19.33	2.14
VRSPAT	21.25	4.00
VRMETA	19.08	1.37
VR(CTRL)	20.91	4.58
MMALL	19.83	1.64
MMSPAT	22.91	8.96
MMETA	20.83	1.19
MM(CTRL)	21.08	2.74
OVERALL	20.65	4.12

Table E-42: Mean age per group

COURSE	FREQUENCY	PERCENTAGE
SCIENCE	46	47.9
ARTS / HUMANITIES	41	42.7
OTHER	9	9.4

Table E-43: Background of subjects per subjects area

	SCIENCE	ARTS / HUMANITIES	OTHER
VRALL	8	3	1
VRSPAT	6	6	0
VRMETA	6	5	1
VR(CTRL)	6	6	0
MMALL	6	5	1
MMSPAT	5	4	3
MMETA	3	7	2
MM(CTRL)	6	5	1

Table E-44: Background of subjects per condition

	MEAN	SD
VRALL	4.41	5.35
VRSPAT	4.33	4.90
VRMETA	4.66	5.19
VR(CTRL)	6.25	7.42
MMALL	13.41	14.70
MMSPAT	3.75	3.27
MMETA	7.66	6.00
MM(CTRL)	13.66	12.30
OVERALL	7.27	8.84

Table E-45: Number of times visited Holyrood Park per condition

	VRALL	VRSPAT	VRMETA	VR	MMALL	MMSPAT	MMETA	MM
LMARK	5.09	11.41	9.10	7.42	3.20	2.90	4.76	5.53
RECOG	3.66	5.91	6.75	5.50	3.25	2.83	4.76	5.00
ID	1.43	5.50	2.35	1.92	-.05	.07	.00	.53
ROUTE	4.24	6.68	3.68	3.35	5.68	4.68	5.92	4.40
SURVEY	3.15	3.27	1.84	1.53	3.96	2.85	2.16	2.74
EGO	1.50	.87	.56	.25	1.50	.45	.42	1.14
GEO	1.65	2.40	1.28	1.28	1.98	2.40	1.76	1.60
QUIZ	3.60	3.50	4.10	4.20	4.40	4.00	4.22	5.08

Table E-46: Comparison of means across tests and conditions among frequent visitors to Holyrood Park (HIFREQ)

	VRALL	VRSPAT	VRMETA	VR	MMALL	MMSPAT	MMETA	MM
HI-FREQ	4.24	6.68	3.68	3.35	5.68	4.68	5.92	4.40
LO-FREQ	6.23	6.01	6.18	5.79	9.00	5.12	7.47	6.14

Table E-47: Comparison between HI/LOFREQ subjects across conditions

RECOG: One way anova [$F(7,40) = 3.73$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT
VRMETA X MMALL

9. Frequency of visits to Holyrood Park (HI/LOFREQ users)

	VRALL	VRSPAT	VRMETA	VR	MMALL	MMSPAT	MMETA	MM
LMARK	8.04	7.00	9.22	8.48	2.53	1.87	3.35	4.47
RECOG	6.00	4.37	6.04	5.9	2.58	3.27	3.33	4.60
ID	2.04	2.63	3.18	2.54	-.05	-1.40	.02	-.12
ROUTE	6.23	6.01	6.18	5.79	9.00	5.12	7.47	6.14
SURVEY	1.86	2.73	2.54	2.85	4.24	2.67	3.90	5.74
EGO	-.16	1.03	.56	.45	.56	.45	1.50	2.00
GEO	2.02	1.70	1.98	2.40	2.12	2.21	2.40	3.74
QUIZ	4.20	4.85	3.65	5.00	3.80	4.00	4.16	4.64

Table E-48: Comparison of LOFREQ subjects across tests and conditions

LMARK: One way anova [$F(7,40) = 4.76$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRALL X MMSPAT
VRMETA X MMSPAT
VR X MMSPAT
VRMETA X MMALL
RECOG: One way anova [$F(7,40) = 4.59$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRALL X MMALL
VRMETA X MMALL
VR X MMALL
VRMETA X MMSPAT
ID: One way anova [$F(7,40) = 3.77$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT X MMSPAT
VRMETA X MMSPAT

10. Analyses for the spatialisation of information hypothesis

TEST	HIVENA/HIMETA	HIVENA/LOMETA
RECOG	2.1333	3.5333
ID	-.8640	.7640
ROUTE	7.2120	6.6800
EGO	1.5000	1.0000
GEO	1.7280	3.0720
QUIZ	4.8800	4.160

Table E-49: Comparison between HIVENA/HIMETA versus HIVENA/LOMETA within MMALL group

TEST	MMALL (HIVENA/HIMETA)	MM(CTRL) NOVENA/NOMETA
RECOG**	2.1333	4.8333
ID	-.8640	.2583
ROUTE	7.2120	5.1283
EGO	1.5000	1.5000
GEO	1.7280	2.4933
QUIZ	4.8800	4.9000

Table E-50: Comparison between MMALL (HIVENA/HIMETA) and MM (CTRL) (novena/NOMETA)

TEST	(LOVENA/HIMETA)	LOVENA/LOMETA
RECOG	5.2857	4.2000
ID	2.5400	.6160
ROUTE	7.0600	2.6900
EGO	.2500	1.2500
GEO	1.4400	2.4000
QUIZ	4.0571	3.6800

Table E-51: Comparison between LOVENA/HIMETA versus LOVENA/LOMETA within VRALL group

TEST	VRALL (LOVENA/HIMETA)	VR(CTRL) NOVENA/NOMETA
RECOG	5.2857	5.7222
ID	2.5400	2.2317
ROUTE	7.0600	4.5742
EGO	.2500	.3542
GEO	1.4400	1.8400
QUIZ	4.0571	4.6000

Table E-52: Comparison between VRALL (HIMETA/LOVENA) and VR (CTRL) (LOVENA/LOMETA)

		VRALL	VRMETA	VRCTRL	MMALL	MMMETA	MMCTRL
RECOG	HIMETA	5.28	6.61	**5.7222**	2.61	4.93	4.8333
	LOMETA	4.20	5.94	5.7222	3.44	3.61	4.8333
ID	HIMETA	2.54	3.89	2.2317	-.66	.91	.2583
	LOMETA	.61	1.92	2.2317	.56	-.63	.2583
ROUTE	HIMETA	7.06	5.35	4.5742	6.45	6.41	5.1283
	LOMETA	2.69	5.35	4.5742	7.12	6.68	5.1283
EGO	HIMETA	.25	.45	.3542	1.50	1.00	1.5000
	LOMETA	1.25	.66	.3542	.87	.78	1.5000
GEO	HIMETA	1.44	2.40	1.8400	1.46	1.95	2.4933
	LOMETA	2.40	1.09	1.8400	2.58	2.08	2.4933
QUIZ	HIMETA	4.05	3.80	4.6000	4.40	4.16	4.9000
	LOMETA	3.68	3.80	4.6000	4.00	4.22	4.9000

Table E-53: Comparison across tests and conditions for HI/LOMETA subjects.

11. Additional analyses

	VRALL		VRSPAT		VRMETA		VR	
	HI	LO	HI	LO	HI	LO	HI	LO
RECOG	4.06	5.38	5.20	4.25	6.14	6.46	6.00	5.33
ID	2.83	.95	4.29	2.17	2.22	3.87	2.96	1.20
ROUTE	4.81	5.54	7.01	4.68	5.35	5.35	4.97	4.02
EGO	1.25	.25	1.34	.25	-.10	1.50	.60	.00
GEO	1.28	2.24	2.12	1.56	1.92	1.50	2.56	.83
QUIZ	3.68	4.05	4.25	4.70	3.80	3.80	5.15	3.50

Table E-54: Comparisons between hi and LO spatial subjects for VR group across all tests

	MMALL		MMSPAT		MMMETA		MM	
	HI	LO	HI	LO	HI	LO	HI	LO
RECOG	2.71	3.46	4.00	2.74	3.72	4.61	4.86	4.80
ID	.21	-.42	-.42	-.74	-.17	.19	1.20	-.42
ROUTE	7.63	5.61	5.79	4.61	7.56	5.57	2.95	6.68
EGO	1.67	.50	1.08	.25	1.29	.45	1.50	1.50
GEO	1.76	2.40	2.77	2.15	2.77	1.28	2.84	2.24
QUIZ	3.88	4.64	4.40	3.86	5.40	3.00	4.88	4.91

Table E-55: Comparisons between hi and LO spatial subjects for MM group across all tests

	VRALL	MMALL	VRSPAT	MMSPAT	VRMETA	MMMETA	VR	MM
RECOG	4.06	2.71	5.20	4.00	6.14	3.72	6.00	4.86
ID	2.83	.21	4.29	-.42	2.22	-.17	2.96	1.20
ROUTE	4.81	7.63	7.01	5.79	5.35	7.56	4.97	2.95
EGO	1.25	1.67	1.34	1.08	-.10	1.29	.60	1.50
GEO	1.28	1.76	2.12	2.77	1.92	2.77	2.56	2.84
QUIZ	3.68	3.88	4.25	4.40	3.80	5.40	5.15	4.88

Table E-56: Comparisons between hi spatial subjects for VR and MM groups across all tests

	VRALL	MMALL	VRSPAT	MMSPAT	VRMETA	MMMETA	VR	MM
RECOG	5.38	3.46	4.25	2.74	6.46	4.61	5.33	4.80
ID	.95	-.42	2.17	-.74	3.87	.19	1.20	-.42
ROUTE	5.54	5.61	4.68	4.61	5.35	5.57	4.02	6.68
EGO	.25	.50	.25	.25	1.50	.45	.00	1.50
GEO	2.24	2.40	1.56	2.15	1.50	1.28	.83	2.24
QUIZ	4.05	4.64	4.70	3.86	3.80	3.00	3.50	4.91

Table E-57: Comparisons between LO spatial subjects for VR and MM groups across all tests

		VR ALL	VR SPAT	VR META	VR (CTRL)	MM ALL	MM SPAT	MM META	MM (CTRL)
RECOG	**HOL**	5.04	4.38	5.75	6.44	2.55	2.80	5.00	4.83
	SER	4.41	5.60	6.54	5.00	3.50	3.40	4.00	4.83
ID	**HOL**	1.43	1.27	1.80	3.15	.56	-1.26	1.43	-.23
	SER	2.35	6.83	3.46	1.30	-.66	.17	-.27	.50
ROUTE	**HOL**	4.35	4.97	7.01	4.90	9.11	4.21	7.34	6.01
	SER	7.01	8.01	4.51	4.24	4.46	5.88	6.41	4.68
EGO	**HOL**	.40	.07	.56	.04	1.29	.42	.25	1.18
	SER	1.18	2.25	.56	.66	1.08	.50	1.00	1.65
GEO	**HOL**	1.56	1.44	.72	1.09	3.33	2.72	.16	2.68
	SER	2.40	2.62	2.26	2.58	.72	1.72	2.40	2.40
QUIZ	**HOL**	3.80	4.05	3.80	4.80	5.00	3.54	4.40	4.70
	SER	4.10	4.88	3.80	4.40	3.40	4.64	4.16	5.00

Table E-58: Holistic and serialist mean performance across all conditions and tests in experiment

APPENDIX E-1

THEMATIC PRESENTATION OF SIGNIFICANT RESULTS FROM EXP. 6

(To be read in conjunction with the discussion of experiment 6)

Theme 1: Affordances of virtual environments for spatial information:

H1: Within group differences for VR and MM

Hivena MM comparison with controls across tests:

RECOG: MMSPAT X MM (CTRL) [$t(20)= -3.18$, $P=0.05$]
EGO: MMSPAT X MM (CTRL) [$t(20)= -2.29$, $P=0.05$]

H2: Between group differences (VR X MM):

Landmark overall:

RECOGNISE: One way anova [$F(7,88) = 6.05$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR (CTRL) x MMALL
VR (CTRL) x MMSPAT

IDENTIFY: One way anova [$F(7,88) = 3.69$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT x MMSPAT
VRSPAT x MMALL

COMBINED SCORE: One way anova [$F(7,88) = 5.15$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT x MMSPAT
VR (CTRL) x MMSPAT
VRSPAT x MMALL

Landmark test (HI-SPAT subjects)

RECOGNISE: One way anova [$F(7,40) = 4.8$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT X MMALL
VR (CTRL) X MMALL

Landmark test (HOLISTIC subjects)

VR(CTRL) x MMALL
VR(CTRL) x MMSPAT
IDENTIFY: One way anova [$F(7,36) = 2.13$, $p<0.06$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMSPAT
COMBINED SCORE: One way anova [$F(7,36) = 3.21$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMSPAT

Landmark test (SERIALIST subjects)

COMBINED SCORE: One way anova [$F(7,44) = 4.21$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT x MMALL
VRSPAT x MMSPAT
VRSPAT x MMETA

HI-VENA-users

LMARK:
One way anova [F(2,21) = 5.03, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRSPAT X MMALL
VRSPAT X MMSPAT
ID:
One way anova [F(2,21) = 4.96, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRSPAT X MMALL
VRSPAT X MMSPAT

HIVENA VR: Independent t-test

QUIZ: VRSPAT X VRMETA [t(14)= 2.03, P=0.062]

LO-FREQ subjects

ID: One way anova [F(7,40) = 3.77, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRSPAT X MMSPAT

Theme 2: Spatialisation of information

Survey text (HOLISTIC subjects)

COMBINED SCORE: One way anova [F(7,36) = 3.63, p<0.01], Post-hoc Tukey-HSD with α=.05:
MMALL x VRSPAT
MMALL x VRMETA
MMALL x VR(CTRL)
MMALL x MMETA

LO-FREQ users

LMARK: One way anova [F(7,40) = 4.76, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRALL X MMSPAT
RECOG: One way anova [F(7,40) = 4.59, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRALL X MMALL

Theme 3: Eclectic pedagogic approach

Landmark test (general)

RECOGNISE: One way anova [F(7,88) = 6.05, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRMETA x MMALL
VRMETA x MMSPAT
VRMETA x MMETA
COMBINED SCORE: One way anova [F(7,88) = 5.15, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRMETA x MMSPAT
VRMETA x MMETA
VRMETA x MMALL

Landmark test (high-spatial subjects)

RECOGNISE: One way anova [F(7,40) = 4.8, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMALL

Landmark test (low-spatial subjects)

RECOGNISE: One way anova [F(7,40) = 2.58, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMSPAT
IDENTIFY:
One way anova [F(7,40) = 2.24, P<0.05], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMSPAT
COMBINED SCORE

One way anova [$F(7,40) = 2.71$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT

Landmark test (SERIALIST subjects)

RECOGNISE: One way anova [$F(7,44) = 3.09$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA x MMALL
VRMETA x MMSPAT
VRMETA x MMETA
IDENTIFY: One way anova [$F(7,44) = 4.01$, $p<0.065$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA x MMALL
VRMETA x MMSPAT
VRMETA x MMETA
VRMETA x MM(CTRL)
COMBINED SCORE: One way anova [$F(7,44) = 4.21$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA x MMALL
VRMETA x MMETA

HI-META group:

LMARK: One way anova [$F(3,20) = 5.28$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
RECOG: One way anova [$F(3,20) = 3.89$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
ID: One way anova [$F(3,20) = 4.23$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL

LO-META group:

LMARK: One way anova [$F(3,20) = 5.56$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
VRMETA X MMMETA
RECOG: One way anova [$F(3,20) = 4.81$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
VRMETA X MMMETA

HI-FREQ group:

RECOG: One way anova [$F(7,40) = 3.73$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT
VRMETA X MMALL

LO-FREQ group:

LMARK: One way anova [$F(7,40) = 4.76$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT
VRMETA X MMALL
RECOG: One way anova [$F(7,40) = 4.59$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMALL
VRMETA X MMSPAT
ID: One way anova [$F(7,40) = 3.77$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT

Theme 4: Role of individual differences

- **High and low spatial subjects**

No direct differences between the two groups.

Within group differences:

HIGH SPATIAL group:
RECOGNISE: One way anova [$F(7,40) = 4.8$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRSPAT X MMALL
VRMETA X MMALL
VR (CTRL) X MMALL

LOW SPATIAL group:
RECOGNISE: One way anova [$F(7,40) = 2.58$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT
IDENTIFY:
One way anova [$F(7,40) = 2.24$, $P<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT
COMBINED SCORE
One way anova [$F(7,40) = 2.71$, $p<0.05$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA X MMSPAT

Knowledge test (SERIALIST subjects)
One way anova: [$F(7, 44) = 0.85$, NS]
INTERACTIONS:
3-way anova found almost significant interaction between:
HI1LO2SP X GROUP: [$F(7, 71) = 2.06$, $p=.059$]
Interpretation: HI-SPATIAL subjects in the VRMETA, VR, MMMETA, MM groups perform better than LO-SPATIAL subjects on this test while LO-SPATIAL subjects in the VRALL, VRSPAT, MMALL, MMSPAT groups perform slightly better than their HISPATIAL counterparts.

- **Holist and serialist subjects**

HOLIST group:
Landmark test
RECOGNISE: One way anova [$F(7,36) = 3.73$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMALL
VR(CTRL) x MMSPAT
IDENTIFY: One way anova [$F(7,36) = 2.13$, $p<0.06$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMSPAT
COMBINED SCORE: One way anova [$F(7,36) = 3.21$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VR(CTRL) x MMSPAT

Survey test
COMBINED SCORE: One way anova [$F(7,36) = 3.63$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
MMALL x VRSPAT
MMALL x VRMETA
MMALL x VR(CTRL)
MMALL x MMETA

SERIALIST group:
RECOGNISE: One way anova [$F(7,44) = 3.09$, $p<0.01$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA x MMALL
VRMETA x MMSPAT
VRMETA x MMETA
IDENTIFY: One way anova [$F(7,44) = 4.01$, $p<0.065$], Post-hoc Tukey-HSD with $\alpha=.05$:
VRMETA x MMALL
VRMETA x MMSPAT

VRMETA x MMETA
VRMETA x MM(CTRL)
COMBINED SCORE: One way anova [F(7,44) = 4.21, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRSPAT x MMALL
VRMETA x MMALL
VRSPAT x MMSPAT
VRSPAT x MMETA
VRMETA x MMETA

INTERACTION EFFECT: Three-way anova [F(7,71) = 2.181, p<0.05], Post-hoc Tukey-HSD with α=.05:
GROUP X HOL1SER2

INTERPRETATION:
VE's benefit holistic learners more than do MM environments (which seem to convey no real advantage for either subgroup).

Survey test

INTERACTIONS:
3-way anova for all groups using scrcorr data:
GROUP X HOL1SER2 [F(7,71) = 3.99, p<0.05]
Interpretation: SERIALISTS perform better than HOLISTS in VR but not in MM
HI1LO2 X HOL1SER2 [F(1,71) = 5.59, p<0.05]
Interpretation: For HISPATIAL subjects SERIALISTS perform better than HOLISTS, this is reversed for LO-SPATIAL subjects
3-way anova for all groups using egocorr data:
GROUP X HI1LO2 [F(7,71) = 2.17, p<0.05]
Interpretation: HI-SPATIAL perform better than LO-SPATIAL in MM but not in VR. Results for MM are mixed
3-way anova for all groups using geocorr data:
GROUP X HOL1SER2 [F(7,71) = 2.44, p<0.05]
Interpretation: SERIALISTS perform better than HOLISTS in VR but not in MM. Results for MM are mixed
HI1LO2 X HOL1SER2 [F(1,71) = 3.86, p<0.05]
Interpretation: For HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, this is reversed for LO-SPATIAL subjects
3-way anova for the VR groups only using scrcorr data: [F(7,33) = 0.55, NS]
3-way anova for the VR groups only using egocorr data: [F(7,33) = 1.94, NS]
3-way anova for the VR groups only using geocorr data: [F(7,33) = 0.50, NS]

Significant main effect between HOLISTS and SERIALISTS investigated further with independent t tests:

EGO: Independent t-test [t(46) = -2.28, p<0.05]
GEO: Independent t-test [t(46) = -2.54, p<0.05]
COMBINED SCORES: Independent t-test [t(46) = -3.35, p<0.01]
INTERACTIONS:
3-way anova for the MM groups only using scrcorr data:
GROUP x HOL1SER2: [F(3,35) = 7.28, p<0.01]
Interpretation: HOLISTS outperform SERIALISTS for MMALL and MMSPAT groups, its reversed for MMMETA/MM groups
HI1LO2 x HOL1SER2 : [F(1,35) = 13.8, p<0.01]
Interpretation: Among HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, its reversed for LOSPATIAL subjects
3-way anova for the MM groups only using egocorr data:
HI1LO2 x HOL1SER2: [F(1,35) = 5.03, p<0.05]
Interpretation: Among HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, its reversed for LOSPATIAL subjects
3 way anova for the MM groups only using geocorr data
GROUP x HOL1SER2: [F(3,35) = 4.36, p<0.01]
Interpretation: HOLISTS outperform SERIALISTS for MMALL and MMSPAT groups, its reversed for MMMETA /MM groups
HI1LO2 x HOL1SER2: [F(1,35) = 8.67, p<0.01]
Interpretation: Among HI-SPATIAL subjects SERIALISTS perform better than HOLISTS, its reversed for LO-SPATIAL subjects

- ## High and low users of spatial features

HIGH-VENA group:

Comparison of the performance of HI/LOVENA use subjects across VRSPAT, MMALL, MMSPAT
LMARK:

One way anova [F(2,21) = 5.03, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRSPAT X MMALL
VRSPAT X MMSPAT
ID:
One way anova [F(2,21) = 4.96, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRSPAT X MMALL
VRSPAT X MMSPAT

Means of HI/LOVENA subjects with subjects from other conditions which acted as controls
HIVENA VR: Independent t test
QUIZ: VRSPAT X VRMETA [t(14)= 2.03, P=0.062]
HIVENA MM COMPARISON WITH CONTROLS ACROSS TESTS
RECOG: MMSPAT X MM (CTRL) [t(20)= -3.18, P=0.05]
EGO: MMSPAT X MM (CTRL) [t(20)= -2.29, P=0.05]

LOW-VENA group: No significant within group differences.

- **High and low users of meta-cognitive features**

HIGH-META group:
HIMETA GROUP:
LMARK: One way anova [F(3,20) = 5.28, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMALL
RECOG: One way anova [F(3,20) = 3.89, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMALL
ID: One way anova [F(3,20) = 4.23, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMALL

LOW-META group:
LOMETA GROUP:
LMARK: One way anova [F(3,20) = 5.56, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMALL
VRMETA X MMMETA
RECOG: One way anova [F(3,20) = 4.81, p<0.05], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMALL
VRMETA X MMMETA

- **Frequent and infrequent visitors to Holyrood Park.**

HI-FREQ group:
RECOG: One way anova [F(7,40) = 3.73, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRMETA X MMSPAT
VRMETA X MMALL

LO-FREQ group:
LMARK: One way anova [F(7,40) = 4.76, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRALL X MMSPAT
VRMETA X MMSPAT
VR X MMSPAT
VRMETA X MMALL
RECOG: One way anova [F(7,40) = 4.59, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRALL X MMALL
VRMETA X MMALL
VR X MMALL
VRMETA X MMSPAT
ID: One way anova [F(7,40) = 3.77, p<0.01], Post-hoc Tukey-HSD with α=.05:
VRSPAT X MMSPAT
VRMETA X MMSPAT

APPENDICES F - I: MATERIALS

APPENDIX F

QUESTIONNAIRE GIVEN TO GEOLOGY STUDENTS ON THE BARN'S NESS FIELD TRIP

This questionnaire assesses student feelings and attitudes towards the quality of teaching provided by conventional field excursions. In addition it is also seeking student opinion on the potential for introducing information technology to this area of geoscience. Please answer all questions to the best of your knowledge as the information you provide will have an impact on the design of future field excursions. Thank-you.

1 PERSONAL DETAILS

1.1 Gender
Male [ ] Female [ ]

1.2 Course / Job
Student (state year of course) [ ] Academic [ ] Other [ ] (please state)

2 CONTENT

2.1 Was it obvious what the objectives of today's fieldtrip were?
Yes [ ] No [ ]
What were they?

2.2 Rate the accuracy of the educational information generally provided to you on the fieldtrip by:
[Circle the appropriate number from 1 (highly accurate) to 5 (completely inaccurate).]
Tutors
[highly accurate] 1 2 3 4 5 [completely inaccurate]
Lecturers
[highly accurate] 1 2 3 4 5 [completely inaccurate]
Other staff members
[highly accurate] 1 2 3 4 5 [completely inaccurate]
Fellow students
[highly accurate] 1 2 3 4 5 [completely inaccurate]
Supplementary material
[highly accurate] 1 2 3 4 5 [completely inaccurate]
How would you improve the accuracy?

2.3 Is the supplementary material (eg notes, lectures, tutorials etc.) provided as background information on a fieldtrip sufficient for your needs?
Yes [ ] No [ ]
What additional information would you like to see provided?

2.4 What is the role of your demonstrator on the fieldtrip?
How would you extend this for your benefit?

3 LEARNING

3.1 Do you receive feedback on your work from a field excursion? [Circle one]
Never Seldom Sometimes Frequently All the time
From where do you most often receive this feedback?
What kind of influence (if any) does this feedback have on the quality of your fieldwork? [Circle one]
no influence negative influence positive influence

3.2 Do you regard the collaborative aspects of a field trip as useful for learning?
Yes [ ] No [ ]
Please state why

3.4 How effective is fieldwork for teaching about the geological structures of a landscape?

Could this be improved in your opinion? Yes [ ] No [ ]
Please state why?

4 **ATTITUDE TO TECHNOLOGY**

4.1 For how many hours per week (approx.) do you browse the Internet and/or send and receive email?

4.2 Please circle those technologies you have used either for educational or entertainment purposes:
World Wide Web, multimedia (eg cdrom titles, drawing packages etc.), virtual reality*, other computer technologies (please specify)?

4.3 Rate each of the following technologies for their *potential* relevance to geoscience field excursions:
[Circle the appropriate number from 1 (highly relevant) to 5 (completely irrelevant).]
World wide web
[highly relevant] 1 2 3 4 5 [completely irrelevant]
Newsgroups
[highly relevant] 1 2 3 4 5 [completely irrelevant]
Multimedia (eg cdrom titles, drawing packages etc.)
[highly relevant] 1 2 3 4 5 [completely irrelevant]
Virtual reality*
[highly relevant] 1 2 3 4 5 [completely irrelevant]
Other computer technologies (please specify)
[highly relevant] 1 2 3 4 5 [completely irrelevant]

*Virtual reality in this context refers to any computer generated three-dimensional world, simulations of the real world, or abstract imaginary worlds that a user interacts with and participates in when using a virtual reality system.

4.4 Would you be willing to have computer technology (of the sort mentioned in Q4.3) supplement some elements of the field excursion?
Yes [ ] No [ ]
Can you identify any areas of the fieldtrip which would benefit in this way? (Please state the type of technology involved)

4.5 If your department offered students a choice between:
a) an ordinary field excursion (like the one today) or
b) a computerised version of the fieldtrip containing all of the same educational information,
Which version would you choose?
Please give reasons for your choice

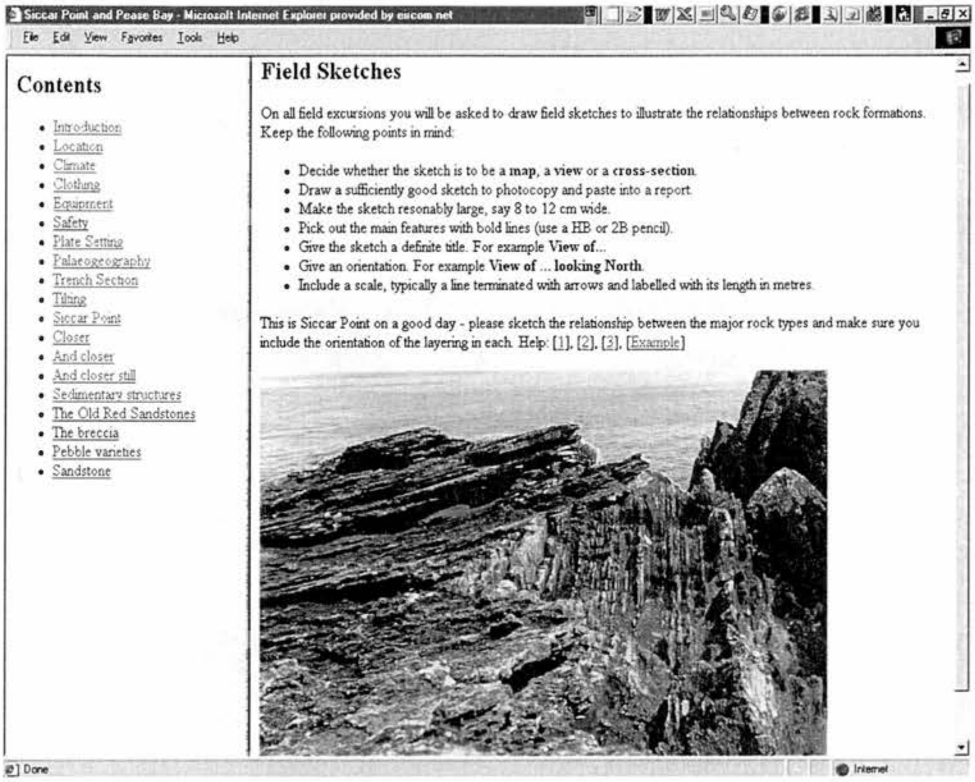
5 **SUGGESTIONS FOR IMPROVEMENT**

5.1 In your opinion how can the field excursion be improved
a) *Without* the use of computer technology
b) *With* the use of computer technology?

5.2 General comments regarding the educational value of field-trips, or this questionnaire

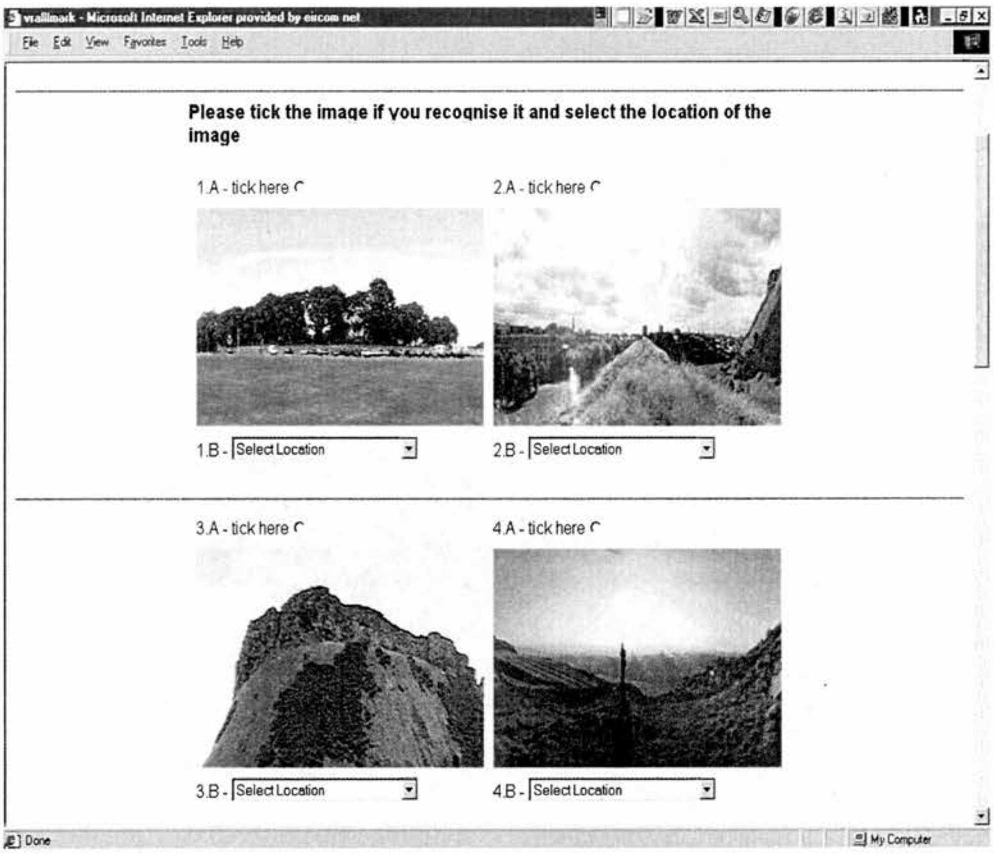
APPENDIX G
SCREEN-SHOT FROM EXPERIMENT 1 (SICCAR POINT EVALUATION)

Appendix G-1: Siccar Point field-course

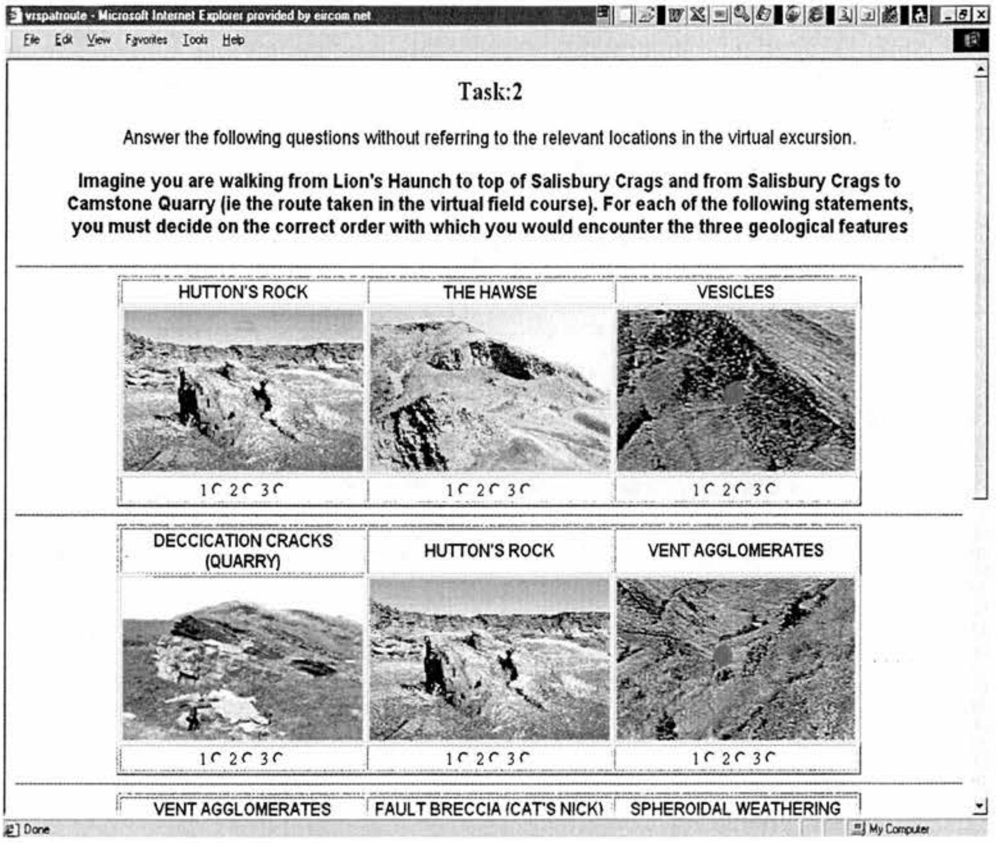


APPENDIX H
SCREEN-SHOTS FROM EXPERIMENT 2 (HOLYROOD PARK EVALUATION)

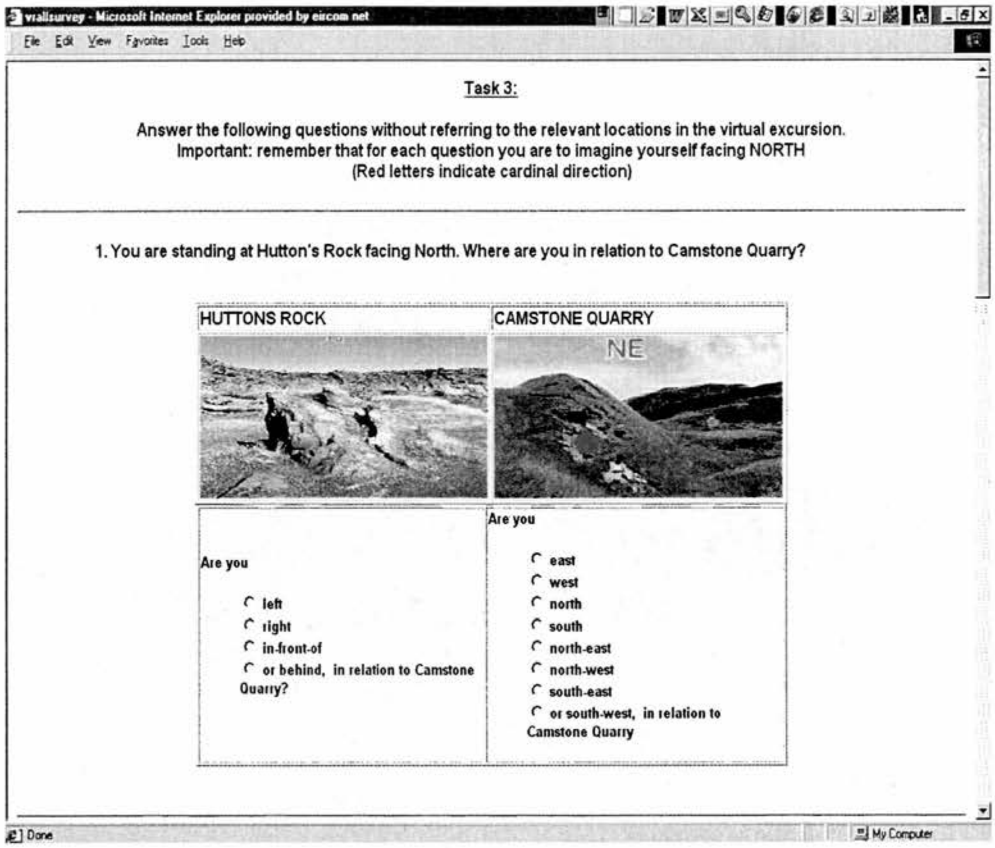
Appendix H-1: Landmark Knowledge Test



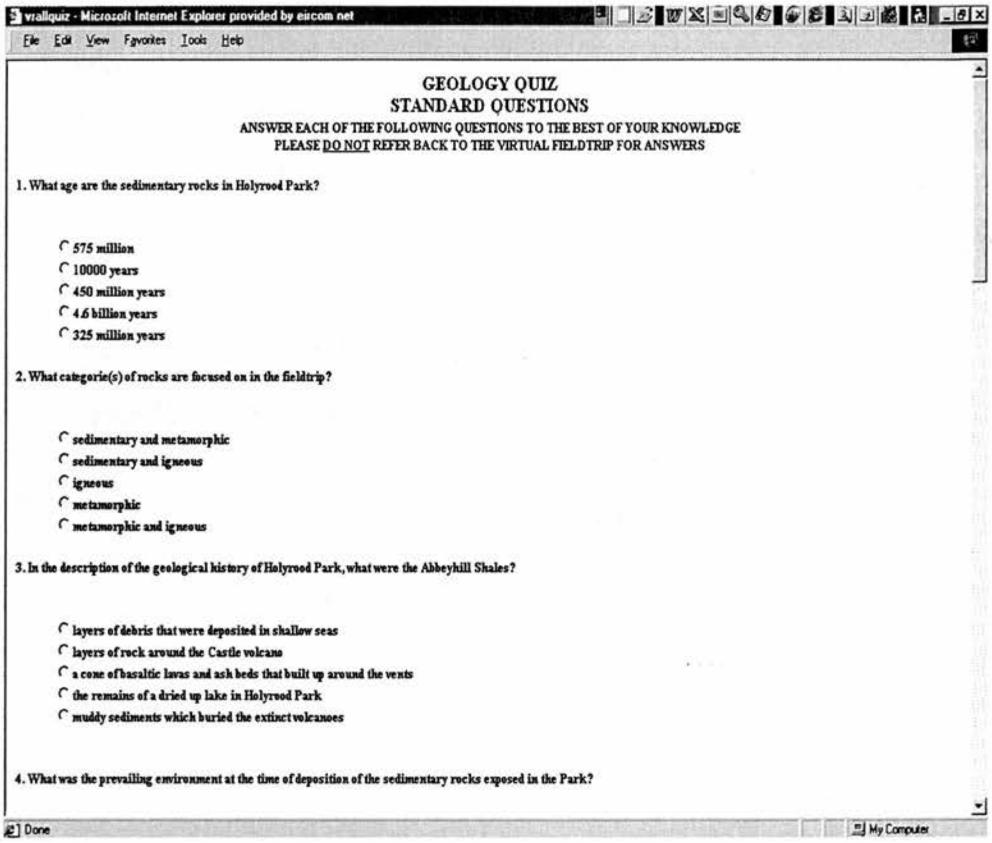
Appendix H-2: Route knowledge task



Appendix H-3: Survey knowledge task



Appendix H-4: Conceptual knowledge task



Appendix H-5: Questionnaire

vrspatquest - Microsoft Internet Explorer provided by eircom net

File Edit View Favorites Tools Help

QUESTIONNAIRE

The purpose of this questionnaire is to discover what you thought of the experiment.
Read each question carefully. Answer all relevant questions as accurately as you can. For most questions simply tick the appropriate choice with your mouse.

NOTE: questions marked with (*) should only be answered if applicable to you.

1. Age:
2. Sex: ○ male ○ female
3. Course of study / job:
4. Year of study:

5. Have you ever been to Holyrood Park (or any part of it) before attempting this virtual field excursion?
○ yes ○ no

6. If you have, please indicate approximately the number of times you have been:

7. Did you enjoy participating in the virtual field excursion?
yes definitely ○ 5 ○ 4 ○ 3 ○ 2 ○ 1 no, definitely not

8.* Did you find the online geology questions helpful for learning about the geology information?
○ yes ○ no ○ not sure

9.* How often did you use the aerial images:
a) to tell you where the geological features are? select choice
b) to tell you where you are? select choice

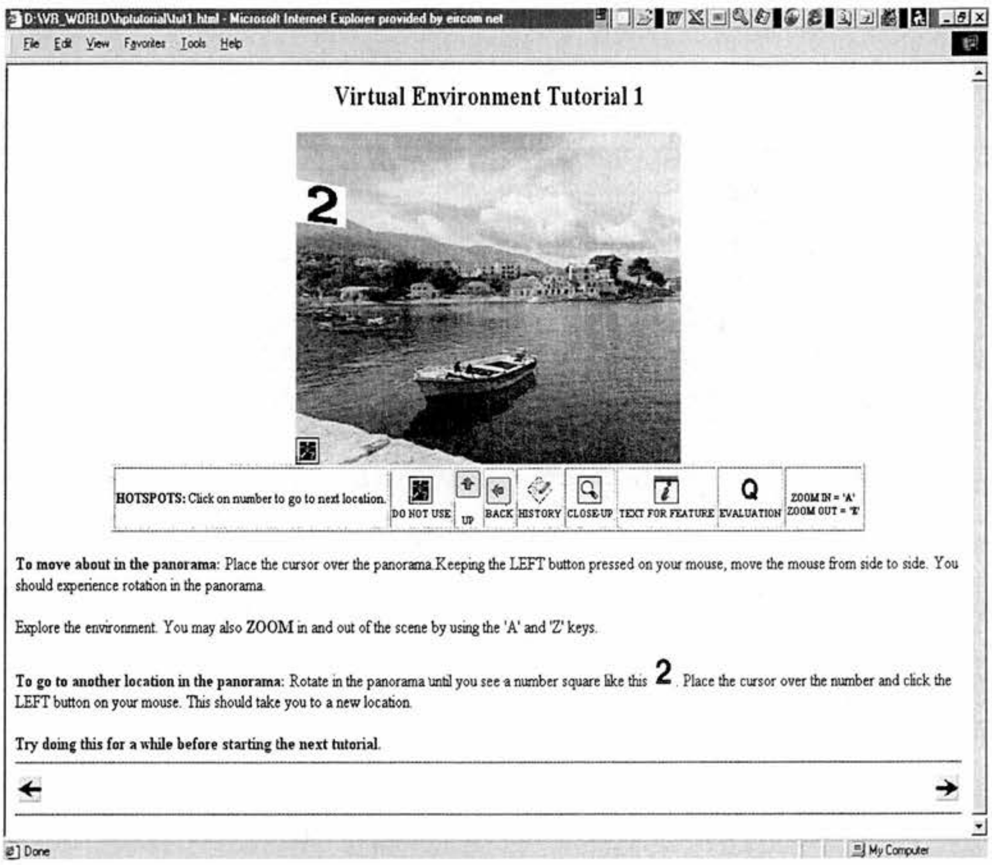
Comments

(please feel free to make any comments, positive or negative, that you would like to add about any aspect of the experiment:

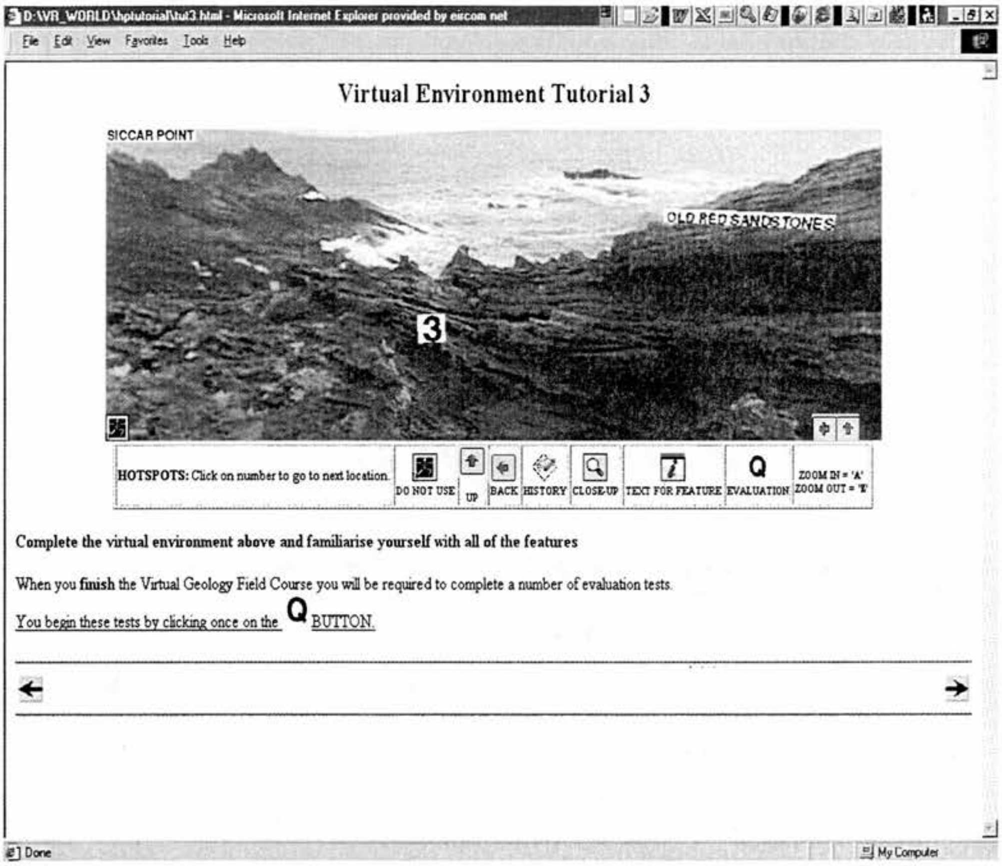
Done My Computer

APPENDIX I
SCREEN-SHOTS FROM EXPERIMENT 6 (HOLYROOD PARK EVALUATION)

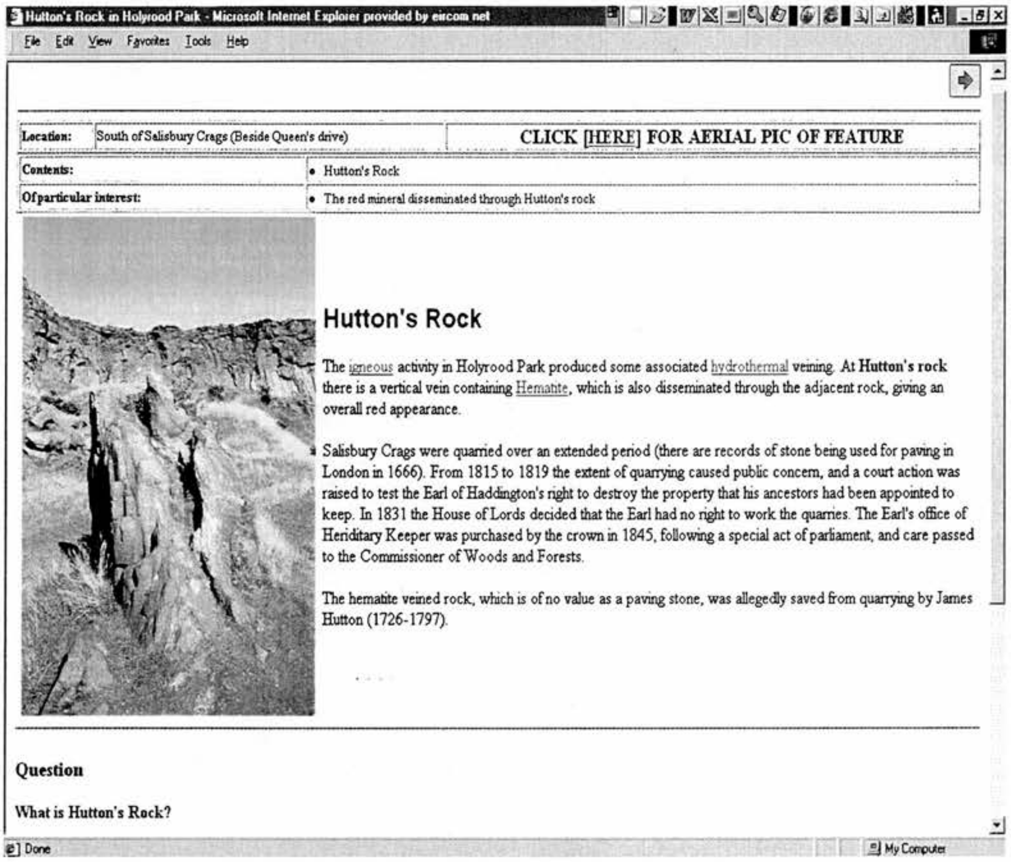
Appendix I-1: The final Holyrood Park virtual environment [Tutorial 1]



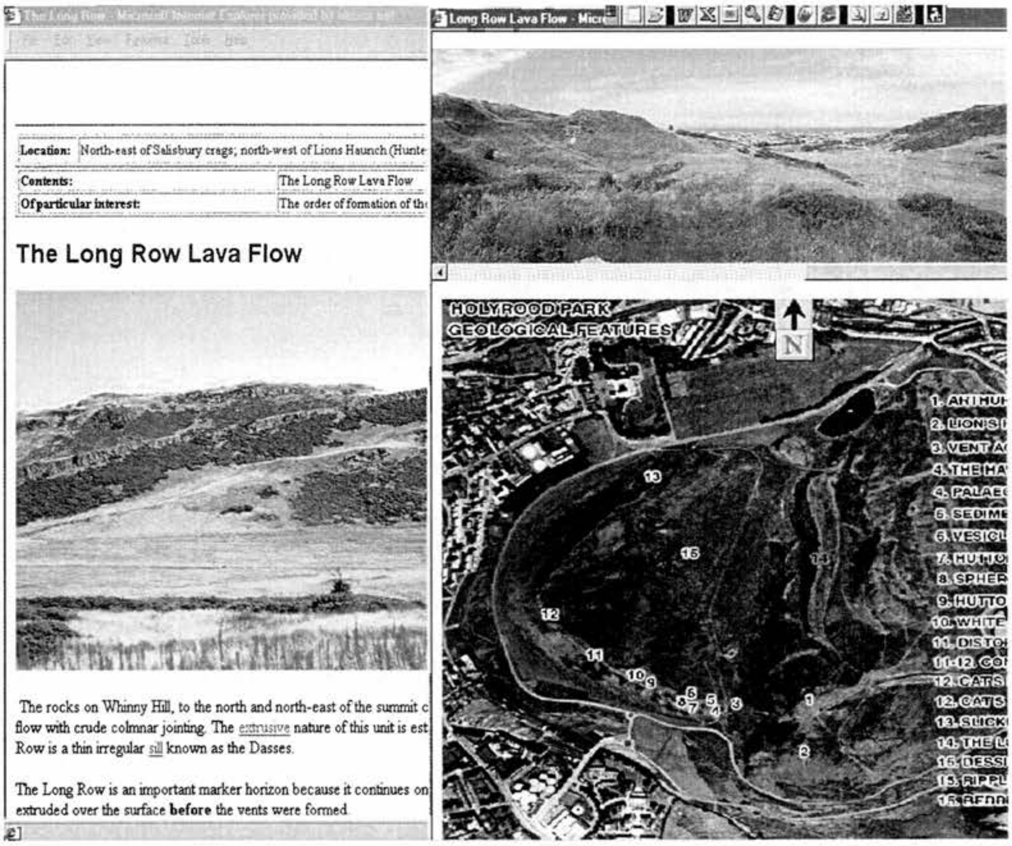
Appendix I-2: The final Holyrood Park virtual environment [Tutorial 3]



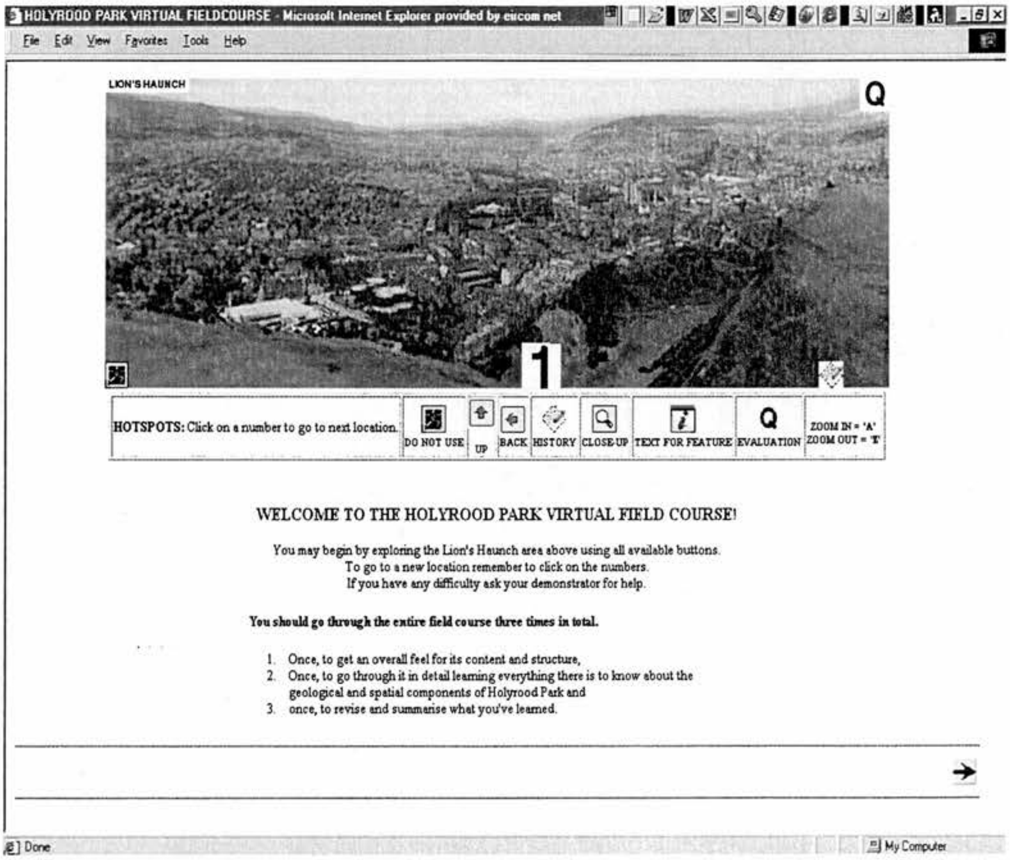
Appendix I-3: The final Holyrood Park multimedia environment [Feature Screen]



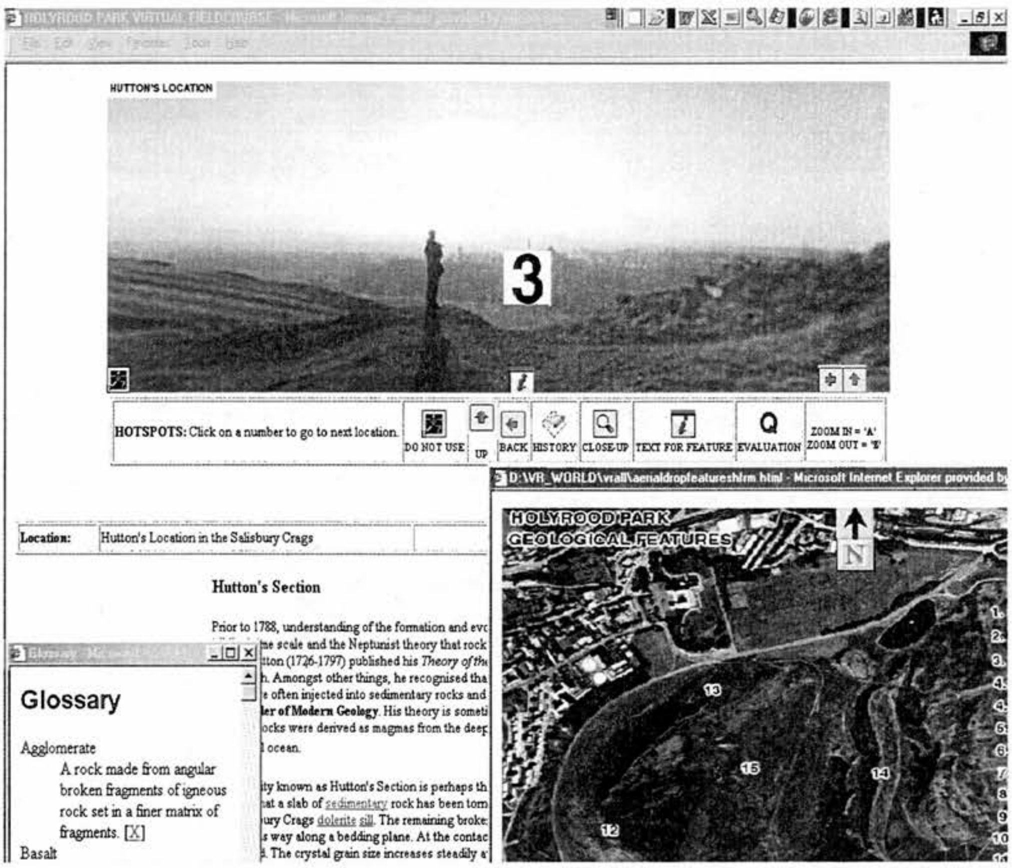
Appendix I-4: The final Holyrood Park multimedia environment [Feature Screen]



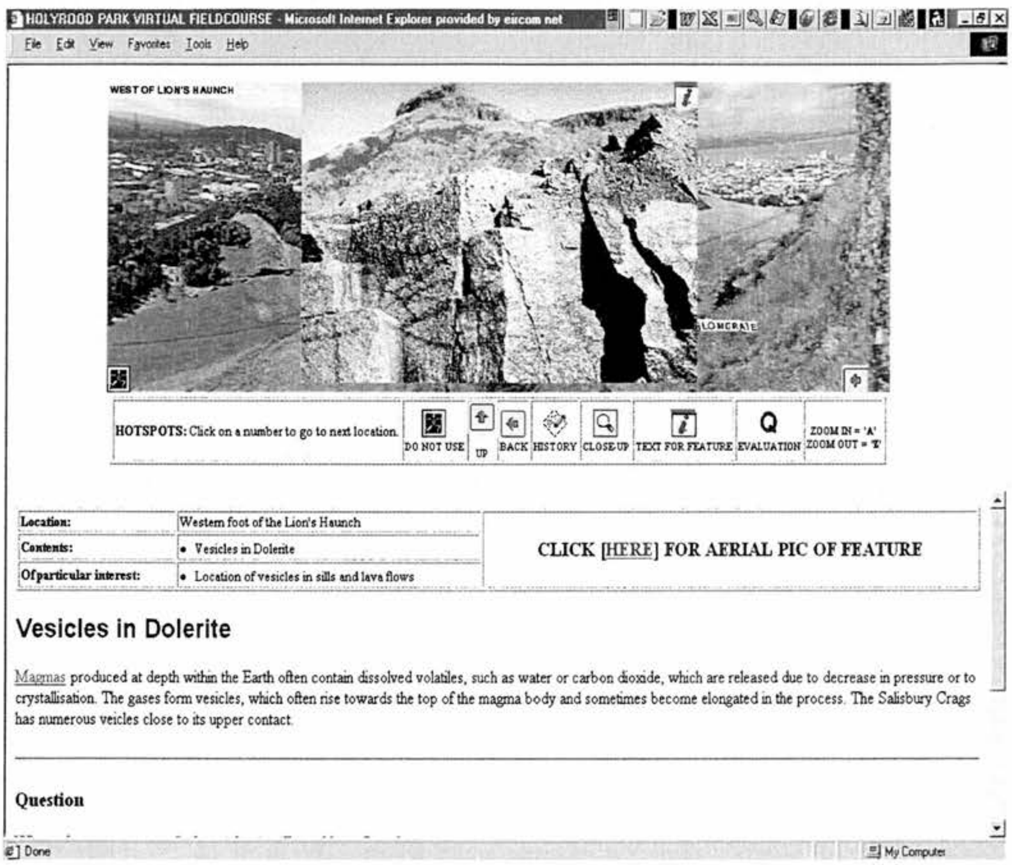
Appendix I-5: The final Holyrood Park virtual environment [Welcome Screen]



Appendix I-6: The final Holyrood Park virtual environment [Feature Screen]



Appendix I-7: The final Holyrood Park virtual environment [Feature Screen]



APPENDIX J

WHAT'S ON THE CD?

CD contents overview

Since the research in this thesis is primarily concerned with how individuals learn using desktop virtual environments, it seemed only appropriate to give the reader an opportunity to experience some of those environments for themselves. To this end, a demonstration version of the VR and MM environments of experiment 6 are included along with their tutorials and evaluation components on the CDROM. In addition to this, three movie clips are included showing fly-through's of Holyrood Park and Siccar Point. Though these were not part of the Ph.D research, they are included to indicate the types of things that were experimented with as part of the VLDTK research but that were ultimately constrained by present day technology. The following is an overview of the CD content:

- LivePicture Viewer plug-in
- Holyrood Park virtual environment tutorial
- Holyrood Park demonstration virtual environment (fully usable)
- Holyrood Park multimedia environment tutorial
- Holyrood Park demonstration multimedia environment (fully usable)
- Series of evaluation tests used in experiment 6 including:
    - landmark knowledge test
    - route knowledge
    - survey knowledge
    - conceptual knowledge
    - questionnaire
- Fly-over movie (MPEG) of Holyrood Park
- Zoom-in movie of Siccar Point
- Fly-over movie (MPEG) of North Berwick (including Siccar Point)

Directory structure on the CD

The CD contains several sub-directories located off the root directory. The directories found on the CD are given in Table J-1.

Directory	Structure on the CD
\ Movies	Contains fly-through movies of: • Holyrood Park [Hpmovie.mpeg] • North Berwick [Spmovie.mpeg] • Zoom-in movie of Siccar Point [Spzoom.mpeg]
\ Tests \ evaluation	Contains the evaluation tests of: • landmark knowledge [vralllmark.html] • route knowledge [vrallroute.html] • survey knowledge [vrallsurvey.html] • conceptual knowledge [vrallquiz.html] • questionnaire [vrallquest.html]
\ Vr_world mmintro.html vrspatintro.html	Contains the Live Picture viewer plug-in (lpv3_22.exe). This must be installed before the virtual environments can be viewed. Contains the introductory web pages for: multimedia field-course [mmintro.html] virtual field-course [vrspatintro.html]
\ mmall mmwelcomeall.html	(Follow links to the tutorials for each version) Contains starting web page for the MM version of the field-course [mmwelcomeall.html]. Follow links to explore the field-course.
\ vrall hpallframe.html	Contains starting web page for the VR version of the field-course [hpallframe.html]. Follow links to explore the field-course.

Table J-1: Directory structure on the CD